JOURNAL OF THE AMERICAN WELDING SOCIETY

VOLUME XI APRIL 1932 NUMBER 4

Annual Meeting Program

Attention is called to the fact that the Annual Meeting Program will operate on DAYLIGHT SAVING TIME which is one hour ahead of Eastern Standard Time.

A large number of the papers to be presented at the Annual Meeting are included in this issue. Others received too late will be published in the May issue. However, preprints will be available of such papers as are received before the meeting. Members desiring to discuss any paper not included in the April issue should at once send their names to the Editor and copies of these preprints from the May issue will be sent one or two days in advance of the meeting.

We have already received indications that this will be a very successful meeting from every viewpoint. Members are urged to attend all sessions promptly as a rather full program has been provided for each day.

Authors of Annual Meeting Papers

There follows brief biographies of some of the authors of the papers to be presented at the Annual Meeting of the Society.

DR. COMFORT A. ADAMS, author of the paper on "Ductility in Metal Structures," is Lawrence Professor of Engineering at Harvard University. He was the first President and is an Honorary Member of the AMERICAN WELDING SOCIETY, and has been the Director of the American Bureau of Welding since its organization in 1919. He was the first recipient of the Miller Medal Award for notable achievement in the art of welding. During the World War he was Chairman of the General Engineering Committee of the Council of National Defence; also of the Welding Committee of the Emergency Fleet Corporation. He is Fellow and Past President of the American Institute of Electrical Engineers, first Chairman of the American Engineering Standards Committee, now the American Standards Association; Past Chairman of the Engineering Division of the National Research Council, Past Chairman of the Edison Medal Committee; Past President of the John Fritz Medal Board of Award.

LEON C. BIBBER, author of the paper on "Experimental Determination of the Values of Fillet Welds in Tension," received his degree as Bachelor of Marine Engineering, University of Michigan in 1916 and Master of Science in 1917. He was formerly associated with the Newport News Shipbuilding and Dry Dock Company. At present he is Senior Welding Engineer, Bureau of Construction and Repair, Navy Department, Washington, D. C.

WALTER RALEIGH CAMPBELL, co-author of the paper on "Production Welding of Light Gage Metal Specialties," was educated at Columbus, Indiana. He served in Automotive Industry—1910–1925 as Draftsman, Tool Supervisor, and General Superintendent; Vice-President, Recording Device Company—1926; Works Manager Absorption Refrigerator Company—1927; Supt. Electrolux Division Servel, Inc., 1928–; Member International Acetylene Association, S. A. E., and T. P. A.

EVERETT CHAPMAN, author of the paper on Ductility in Machine Construction, graduated from the University of Michigan in Electrical Engineering, subsequently taking a Master's Degree in Physics. After teaching school for one year at Purdue University he went with the Lincoln Electric Company. He has been associated with Lukenweld, Inc., for the last two years as director of Engineering and Research.

CARL DEGANAHL, author of the paper on "Spot Welding," received his education at the Massachusetts Institute of Technology. He joined the Midway Oil and Storage Company of Kent, England, and became its Works Manager. He was with this Company for the period of 1924–1929. He is now President of Fleetwings, Inc.

P. W. FASSLER, author of the paper on "Modern Spot and Relief or Projection Welders," has spent twenty-five years in the welding industry, is acknowledged as one of the leading resistance welding authorities. For many years Mr. Fassler was the owner of the largest welding machine company in Europe.

EDWARDS R. FISH, author of the paper on "Why Ductility of Welds Is Important in Welded Pressure Vessels," graduated from Washington University, St. Louis, Mo., with M.E. Degree in 1892. Was in charge of Timber Testing Lab., Washington University, from 1892–1893; Draftsman, Railway Department, General Electric Co. in 1893; was connected with Heine Boiler Co. from 1893–1927. At present is Chief Engineer of Boiler Division of the Hartford Steam Boiler Insp. & Insurance Co. Author of numerous papers.

CAPTAIN J. O. GAWNE, author of the paper on "Welding on U. S. S. *New Orleans*," is a graduate of the United States Naval Academy in 1905. Sent to the Massachusetts Institute of Technology in 1907 for graduate study for the Construction Corps of the Navy. Received degree of Master of Science in 1910. Served at various Navy Yards and in the Bureau of Construction and Repair of the Navy Department in connection with repairs to naval vessels and their construction. From 1926–1929 served as Assistant Naval Attache, American Embassy, London, Paris, Berlin and Rome. Now in charge of the hull construction of the cruiser *New Orleans* and the destroyer *Hull* at the Navy Yard, New York.

Member of the Society of Naval Architects and Marine Engineers and the Institution of Naval Architects of Great Britain.

GORDON G. HOLBROOK, author of the paper on "Welded Barge Construction at the Federal Shipbuilding and Dry Dock Company," graduated from the Massachusetts Institute of Technology in the Department of Naval Architecture and Marine Engineering in 1910. After a few years of research work and teaching at the Institute, he became connected with the Bath Iron Works, Bath, Maine, remaining until 1917. For four years he was with the Bethlehem Shipbuilding Corp. at the Fore River Plant in Quincy, Mass., in charge of Hull Construction. In the fall of 1920 he became connected with the Federal Shipbuilding and Dry Dock Company as Hull Superintendent and is now General Superintendent.

IRA T. HOOK, author of the paper on "Welding of Extruded Metal," has been Research Engineer for The American Brass Company since 1924, and has done considerable pioneering work in the welding of the copper alloys. Previous to that, he taught strength of materials at Yale University, while for the first six years after graduating from the University of Michigan in 1913, he was physical test expert on the staff of the General Motors Corporation.

CHARLES H. JENNINGS, author of the paper on "Ductility in Arc Welds with Some Reference to Strength Values," was graduated from the Mechanical Engineering Dept. of Iowa State College with a degree of Bachelor of Science in M.E. After graduation he became connected with the Westinghouse Elec. & Mfg. Co. as a graduate student, and later as an engineer in the Mechanics Division of the Research Laboratories. Since his connection with the Research Laboratories his efforts have been confined to the study of the fundamental investigation of the physical properties of arc welds and the design of welded articles. He is a Junior Member of the American Society of Mechanical Engineers, an Associate Member of the AMERICAN WELDING SOCIETY, Chairman of the Welding Society Committee on "Revising the Arc Welding Manual," and Chairman of the Pittsburgh Section of the Fundamental Research Committee of the American Bureau of Welding. He is author of numerous articles on welding, including such subjects as: fatigue and impact properties of

arc welds, strain relief of welded structures, stress analysis of fillet welds, and strength investigations on welded beam connections.

JOHN A. MATHEWS, author of the paper on "Cause and Cure of Intergranular Corrosion in Austenitic Steels," is Vice-President and Director of Research of the Crucible Steel Company of America. His metallurgical education was obtained at Columbia University and Royal School of Mines, London, England. His connection with the steel industry covers thirty years, during which time he has given particular attention to the electric furnace process and the manufacture and applications of alloy steels.

His company pioneered in America the manufacture of austenitic chromium nickel steels and has manufactured the plain chromium stainless irons and steels for a somewhat longer period. The author's work on austenite and austenitic steels, described in the Howe Memorial Lecture before the American Institute of Mining and Metallurgical Engineers in 1925, won for him the Robert W. Hunt Gold Medal.

H. F. MOORE, author of the paper, "Ductility: What Is Its Significance? How Test for It?" graduated from Cornell University and received his Master's Degree from the same university. He has taught at Cornell University, University of Wisconsin, Madison, Wis., and since 1907 has been Research Professor of Engineering Materials, Engineering Experiment Station, University of Illinois. He has invented a number of testing devices and instruments. Is author of "Text Book of Materials and Engineering," and "Fatigue of Metals," as well as a large number of articles. Is a past president of the A. S. T. M. and in 1930 received the Medalist of the American Iron and Steel Institute.

D. ROSENTHAL, author of the paper on "Effects of Ductility on Welded Connections and Methods of Its Measurements," is a graduate Civil Engineer of the Brussels University. At present he is "Chef de Travaux" (Assistant Professor) at the Laboratory for Testing Materials at the University. His principal research interest involves: stress and strain distribution in fillet welds; testing of welded deposits; design of welded joints submitted to bend. He collaborated with Prof. Dustin, the Head of the Laboratory for Testing Materials at Brussels University, whose paper, "Principles of Arc Welding," was awarded the second prize in the Lincoln Competition 1929.

ROBERT S. TAYLOR, co-author of the paper on "Production Welding of Light Gage Metal Specialties," received his B.A. Degree in 1919; M.A. in 1920; Ph.D. in Physical Chemistry in 1923; was Research Associate at Massachusetts Institute of Technology 1923–1924; Technologist for the U. S. Bureau of Fisheries 1924–1926; Research Engineer for Electrolux Servel and Servel Inc. since 1926. Member of American Chemical Society, American Gas Association and Sigma Xi, Phi Lambda Upsilon.

CHARLES LORNE WADDELL, author of the paper on "Engineering and Economic Study of Arc," received his degree of B.S. in Electrical Engineering at Worcester Polytechnic Institute, Class of 1918. He was Ensign in Engineering, U. S. N. R. F. in transport duty 1918–1919. Since 1919 has been associated with Worthington Pump and Machinery Corporation at the Harrison, N. J., plant. Held position as Student Engineer, Draughtsman, Assistant Condenser Engineer, Research Engineer and Welding Engineer.

SECTION ACTIVITIES

BOSTON

Over 250 members and guests attended the regular meeting of the Bostion Section on March 10th. The meeting was held at the Club House of the United Shoe Machinery Corporation, Beverly. A program was given by the John A. Roebling's Sons Company, who sponsored the meeting. The program was divided into two sections. The opening section contained two papers, both on the subject of arc welding applied to ship building. Mr. W. P. Hough of the Bethlehem Shipbuilding Corporation, Ltd., presented an excellent paper on the use of electric welding on the S. S. *Mariposa*, of the Matson Line. Over 60,000 lb. of electrode wire were used in the fabrication of this vessel that is now sailing the Pacific.

The second paper was presented by Mr. J. A. Potter of the U. S. Navy Yard, Charlestown, and was an interesting discussion of the building of a 65-foot arc welded tug boat. The speaker pointed out some of the problems encountered in the project, and the solutions obtained. The Boston Section, on a visitation trip to the Navy Yard last October, saw this boat in the process of erection, and the report of this meeting in an earlier issue of this Journal contains interesting information about the boat. After the necessary trial runs have been made, the tug boat will be sent to the Portsmouth, New Hampshire Navy Yard for service.

The last half of the meeting consisted of four reels of motion pictures showing the construction of the George Washington Bridge across the Hudson River, and made a fitting conclusion to the March meeting of the Section.

A program consisting of Liquid Air Demonstrations, motion pictures and a talk on industrial pipe welding, is being planned for the next meeting on April 15th, in the Rooms of the Engineering Societies.

CHICAGO

At a meeting of the AMERICAN WELDING SOCIETY, Chicago Section, which was held Friday evening, March 4th, the general subject was "Gas Welding in Production." The first paper was presented by H. O. T. Ridlon of the Barrett Hardware Company, Joliet, Ill., on the subject of "Production Welding with the Oxy-Acetylene Torch." This included an interesting discussion on the importance of setting up adequate facilities when the torch is used in production work, the necessity for having equipment of the proper capacity and design for the work to be done, and the relation between the proper design of jigs and fixtures and efficiency of operation. A number of lantern slides were used to illustrate the various points brought out in the paper.

This paper was followed by a talk on the Lindeweld process given by J. W. Haygood of the Linde Air Products Company. M. Haygood's talk was supplemented by a motion piture showing the Lindeweld process in detail, and an actual demonstration of the process making a butt weld on 10-inch standard pipe.

During the meeting nearly thirty welded coupons were turned in for X-ray examination. This X-ray inspection is to be made during the month of March, and a complete report and discussion of all of the coupons will constitute the program for the April meeting of the Chicago Section.

(Continued on page 62)

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-161. Welding Engineer wishes position. Will train welders to quality work, assist in design and cooperate with sales department. Employment for limited time satisfactory.

A-162. Arc welder desires position in salvaging work. Has had considerable experience and can furnish references.

A-163. Combination arc and gas welder desires position. Have had six years' experience with the Consolidated Gas Company in making general repairs; one and a half years with the White Motors Co.; three years with the Lago Petroleum Corp., and a year and a half with the Drilling and Exploration Co.

A-164. Executive sales engineer and consultant available. Have had ten years' experience in the welding field as sales engineer and consultant. Familiar with engineering problems particularly in arc welding field. Have had extensive experience in executive side of sales. Can take charge of a sales and distribution program.

Welded Barge Construction at Federal Shipbuilding and Dry Dock Company

By GORDON G. HOLBROOK

✦This paper will be presented at the Annual Meeting of the American Welding Society to be held in New York, April 27th to 29th, by Mr. Gordon G. Holbrook, General Superintendent, Federal Shipbuilding and Dry Dock Co.

ELECTRIC welding in the past ten years has made substantial progress in many fields of construction. It was introduced in shipbuilding in the previous decade, but due to the necessity for haste in the war program and the lack of available design data, adequate equipment and trained operators, some unfavorable results were obtained. For the next few years the use of welding was confined principally to corrective work. Recently, a revival of constructive welding in shipbuilding has taken place, but at a much more conservative rate. In large vessels, with the notable exception of naval work, electric welding has been used principally in

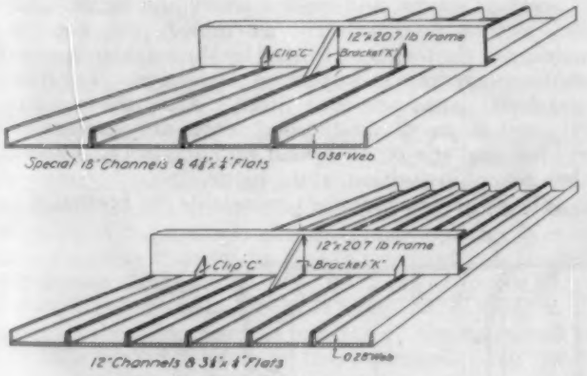


Fig. 1—Typical Sections

the design of minor parts and fittings. In the design of small craft, however, several important methods have been employed to realize the benefits of electric welded construction.

One of these designs is offered by the Federal Shipbuilding and Dry Dock Company of Kearny, New Jersey. This type is based on the Holbrook system of electric welded construction and is covered by patents in the United States and Canada. The basic principle of this design is the joining of rolled structural channels with intermediate flat bars, all united with a double seam of electric welding. Transverse framing members run continuously over the toes of the channels, and are widely spaced. This method produces a structure of great local and longitudinal stiffness. The steel shapes generally used are the 18 inch x 38.4 lb. Carnegie channel C 60, specially rolled for the purpose, and the 12 inch x 20.7 lb. Carnegie channel C 2. The intermediate flat bars are designed to conform to the width of

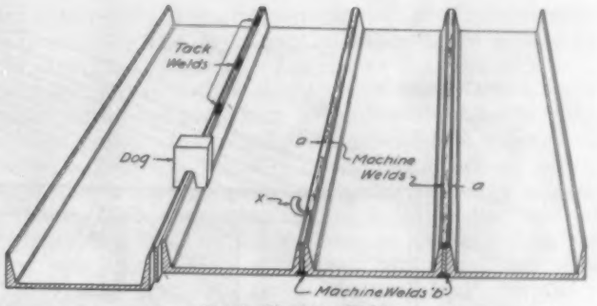


Fig. 2—Machine Welds

the flanges of the channels, and are usually $^1/_4$ inch in thickness. The frames are of 12-inch or 15-inch channel sections spaced about six feet apart. These frames are fastened to the welded toes of the bottom channels by clips C or brackets K welded as indicated in Fig. 1.

The weld at "a" and "b" joining the channels and flat bar in Fig. 2 may be made either by hand or machine welding. On the first Federal barge these seams on the bottom and sides were welded by hand, but since that time the welding has been performed by the shielded carbon arc process. The welding head, an "Electronic Tornado" manufactured by the Lincoln Electric Company, is mounted on a self-propelled carriage designed and built at the Federal plant. This machine is fully automatic in its operation, and produces a uniform weld of high tensile strength and ductility. The speed of travel in service is from sixty to eighty feet per hour.

In adapting the use of the automatic welding head to our purpose, many tests were made to determine the best operating conditions of current values, arc gap, speed of travel, etc.; and these factors are maintained at the most desirable setting. Transverse test pieces through the automatic welded seams have been made and subjected to tensile and bend tests. In the case of the tensile tests, the specimens broke through the web of the channel rather than in the weld. Test strips have been cut from the weld as shown at "X" in Fig. 2. These strips bend through 180 degrees around a half-inch diameter pin without evidence of failure. One advantage of the shielded carbon arc process is that slag, scale and other impurities are floated to the surface of the weld in the puddling action.

The hand welding employed on the Federal barges is carefully calculated and clearly shown on the detailed plans both as to size and amount. Direct current equipment of modern design is used, and the proper current values are set by a competent supervisor. The electrodes used are bare wire. The hand operators themselves are tested by making standard test pieces in the three positions, flat, vertical, and overhead. A first-class welder must make three test pieces in each position with an average tensile strength through the weld of

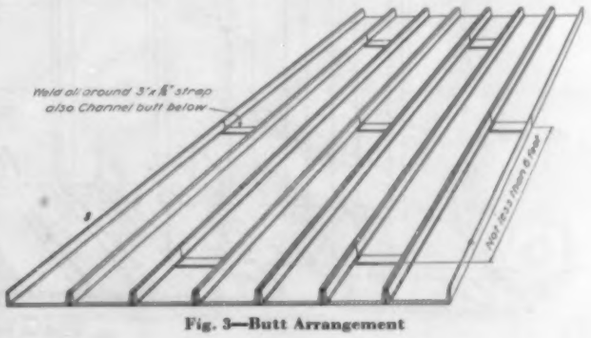


Fig. 3—Butt Arrangement

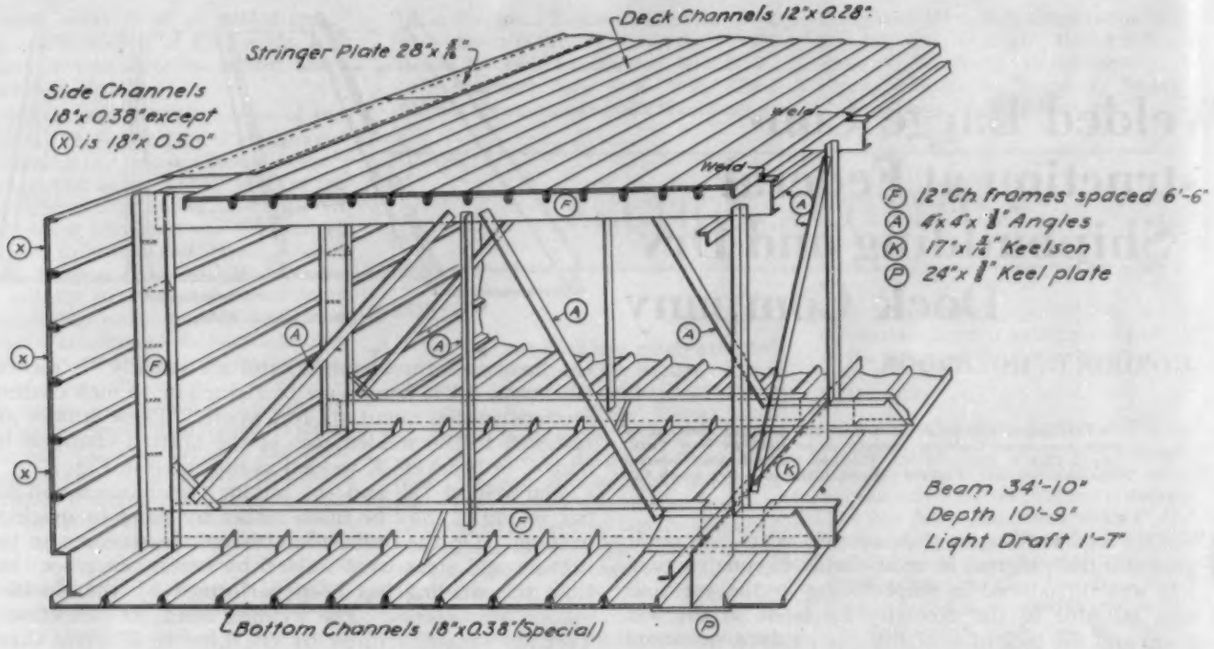


Fig. 4—Half Section

45,000 lb. per square inch. Our welders generally attain from five to ten thousand lb. per square inch above the minimum requirements. No welder is employed on barge construction who has not first qualified in meeting the tests.

The general procedure in constructing the Federal barges is as follows: The channels for forming the bottom of the barge are distributed on skids, toe up. The flat bars are tack welded to one flange of each channel with care to see that the projection at the heel is correct. This projection is important; both to afford a guide for the welding machine when operating on the heel side, and also to produce a reinforced weld at this point. Adjoining channels are then clamped tightly together by means of a special dog shown in Fig. 2, and held by tack welds over the toes. The channels are between thirty and forty feet in length, and the butts are so distributed that there are at least two continuous channels between butts in the same transverse line. The butts in adjacent channels are not closer than six feet as indicated in Fig. 3. The butts are strapped with flat bar in the inside of the channel as shown, and welded above and below. After the section is completely assembled, the automatic welding at the toes is performed by the machine operating continuously from end to end of the section. The frames and butt straps are then fitted. After the section is reversed on the skids, the heel seams are automatically welded, and the butts welded by hand. The section is then placed in position on the barge.

It has been our practice to assemble the bottom of the

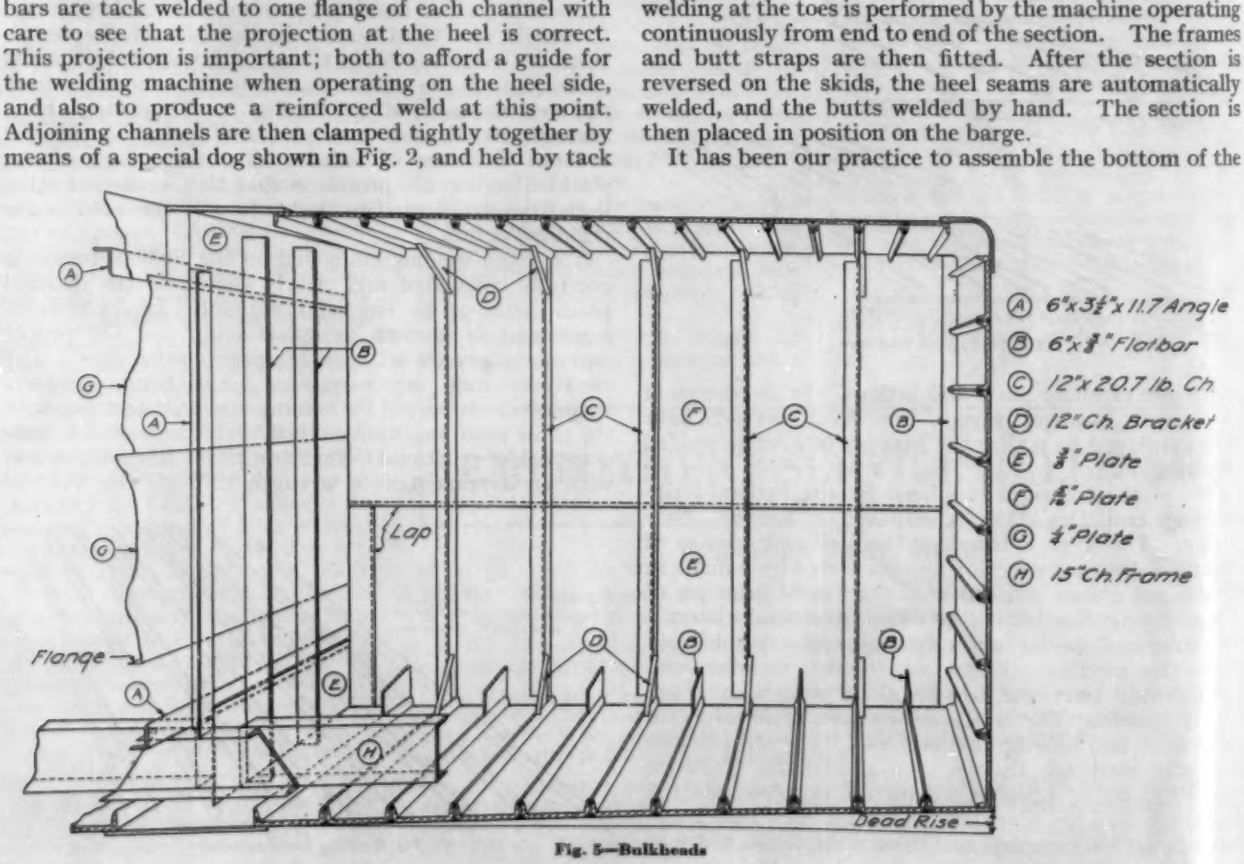


Fig. 5—Bulkheads

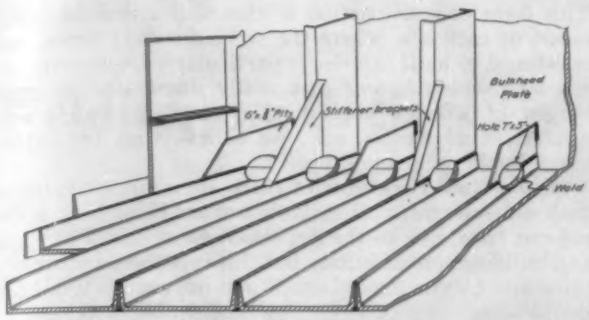


Fig. 6—Drain Holes

barges in sections of half the beam of the barge and the full expanded length. The sides are assembled in one piece. When the size of the barge is such that the sections so arranged are too large to handle conveniently, the assembly may be divided into two or more sections along a fore and aft line, as well as transversely, with a proper shift of butts in the latter case. The joint between sections on the barge are performed either by hand or machine welding as the construction may permit. A closing plate is often used at the center line as a flat keel shown in Fig. 4. This plate is hand welded in position with a double seam of weld at each edge. In order to provide extra stiffness to the side to resist damage or abrasion, the webs of certain of these channels are often increased in thickness. This method eliminates the need of any external fenders, and still presents a smooth side on the barge. The manner in which the side fits inside the outer flange of the bottom channel is indicated in Fig. 4.

Where bulk liquid cargoes are to be carried, bulkheads are provided in the barges. The fore and aft bulkheads may be of swash type shown in Fig. 5. The transverse bulkheads are oiltight and formed of plates with angle or channel stiffeners as indicated. In order to provide efficient drainage, such barges are usually given about a three-inch deadrise on the bottom. Limber holes are cut through the standing flanges of the bottom channels, and reinforced as shown in Fig. 6. By this means easy stripping of the tanks is afforded; and drainage is even more complete than in the case of a bottom constructed with lapped strakes of plating. In cases where the barge is not intended for bulk liquid cargo, it is possible to assemble the deck channels in place on the barge and so eliminate the toe welding on these channels. No loss of strength results, and a convenient method of construction is provided. The decks may be either flat or a sheer at the ends may be given. The rise at the rake ends may be made either with a single or double knuckle; or a rolled transverse plate may be employed to give a curve at this point. A general arrangement of a typical oil barge is shown in Fig. 7. Deck houses, derrick posts, expansion trunks, manholes, etc., are completely welded.

There have been nine barges built at the Federal Shipbuilding and Dry Dock Company to this design, the first one having been completed in the fall of 1928. Two of these are in the sand and gravel trade, two carry molasses in bulk, one is a derrick lighter, and four carry gasoline in bulk. Three of the latter type are 175 ft. x 36 ft. x 12 ft. 7 in. in size and 10,000 barrels in capacity. All the barges built are reported to have given the utmost satisfaction in service. The fact that the four gasoline barges are operated by the same owner, the first going into service in the spring of 1929 and the last one being delivered in the spring of last year, is a gratifying endorsement of their advantages. The American Bureau of Shipping has approved the design and supervised the construction of the gasoline barges. These barges are also approved by the U. S. Steamboat Inspection Service. Lloyd's Register of Shipping has given general approval to the system, and in particular to the design of a 20,000-barrel gasoline barge. This design has also been approved by the American Bureau of Shipping.

The outstanding advantage of the welded barge over the barges of conventional riveted construction lies in the absence of rivets to become loosened, leak, and corrode away. The Federal design permits the extensive use of full automatic welding in the important shell and deck seams. It is worthy of note that from 67 to 80% of the entire welding on a barge may be done in this manner, assuring uniform and precise workmanship. Observations taken on the barges in service indicate that the welding metal is notably less subject to corrosion than the rolled metal in the joined members. This may be due to the floating of the slag to the surface in the puddling action of the weld, thus shielding the weld metal from attack.

The basic design of the joint between the channel members was evolved with the particular object in view of obtaining tight metal contact. The assembly dogs, mentioned before, wedge the flanges and intermediate flat bars firmly together before welding—which is a condition of utmost importance in relieving the weld of undue strains. All underwater joints are sealed with

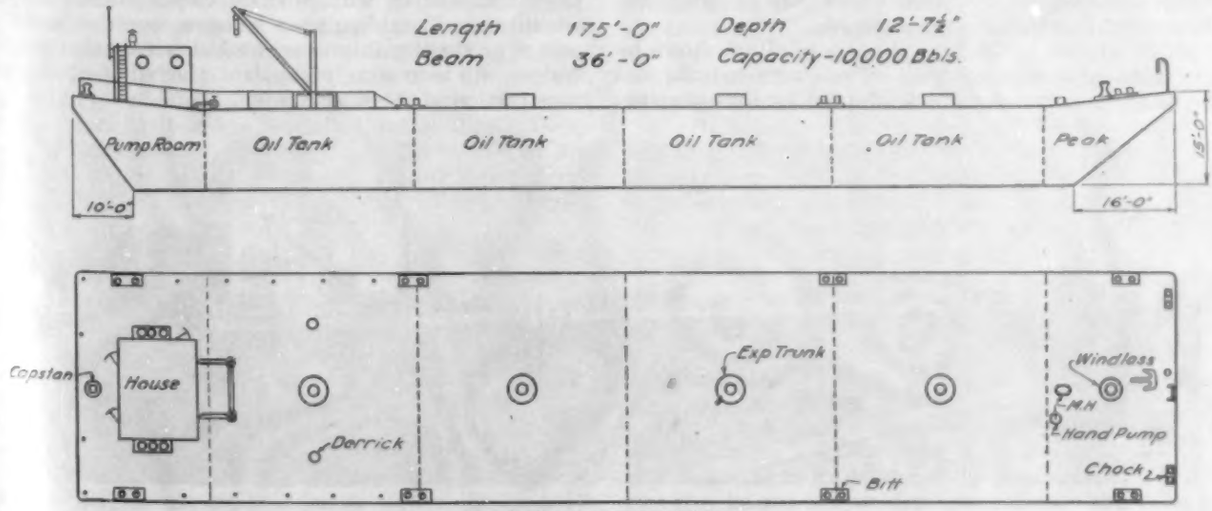


Fig. 7—Arrangement of Oil Barge

Fig. 8—Deck View of Sand Barge

two seams of welding, separated sufficiently to avoid interfering stresses. The united flanges of the channels are very efficient in adding strength to the shell and decks, to resist local, as well as longitudinal, strains. The wide spaced frames lend themselves readily to the transverse and longitudinal diagonal bracing designed to resist racking. The smooth bottom without projecting laps or butts affords easy towing, and the flush deck shown in Fig. 8 is of great advantage for shoveling or carrying a deck cargo. The use of the flat bar filler is a

Fig. 9—Typical Lighter Hull

distinct advantage over other designs employing channel construction, in that the thickness of the flat bar may be varied to suit the actual rolled depth of the channels. This eliminates any matching up of channels in the original assembly; and in the case of repair work, any channel of the same nominal size as the original may be substituted. In the case of damage, repairs can be readily effected at any place where flame cutting and electric welding facilities are available.

Much interest in this type of barge has been shown by operators engaged in carrying oil products in bulk, and the design is particularly well adapted for that purpose. This form of construction is also well suited for dump scows or carfloats, where the service is very severe and resistance to local injuries is particularly important. In the field which is now principally dominated by small barges of wooden construction, such as deck scows, lighters, sand barges, etc., we believe that the welded barge has a great opportunity.

In the New York district there are a large number of such wooden craft. Relatively few are being built at the present time, due to the depressed condition of shipping and building construction; but this fact should accelerate the market when general conditions improve. Wood as a material for barge construction is becoming more difficult to obtain and consequently higher in price. Steel on the contrary, is now available at the lowest price in many years. Wooden barges require constant caulking, and rapidly lose buoyancy in service. Welded steel barges require no maintenance except periodic painting. They are much lighter when first built and do not lose carrying capacity with age. The limitations of wooden construction keep the economical length from 100 to 150 feet, but steel barges are readily constructed up to any size, of advantage to operate. Internal divisions are impractical with wooden construction; but with the welded barge, bulkheads may be introduced to make it actually unsinkable if desired. A more favorable insurance rate can be obtained on a welded steel barge than on a wooden one; and the time lost and expense involved in surveys for minor fender and corner damages or general straining can be eliminated. Particularly in the sand and gravel trade, as the distances from the supply to the market increase, economy in towing becomes an important factor, and larger, easier handled barges will become more attractive.

With regard to the cost of construction of the Federal barge, for coastwise and harbor service, we believe that this type is somewhat more economical to build than the riveted barge of conventional design as built in coastwise shipyards. The tendency in developing welded designs is to stress the saving in weight permitted by the substitution of welding for riveting; thereby reducing the material costs. In the Federal design for seaboard service conditions, no attempt is made to lighten the scantlings; in fact, the amount of steel used is slightly greater than in the same barge of riveted construction. The principal economy effected in this design arises from the use of automatic machine welding with its high rate of production, and uniformly superior quality. On a production basis, the Federal barge may be built at a price competitive with wooden construction. As the advantages of welding gain wider recognition and the cost of production improves, we feel certain that welded designs will increasingly supplant riveted steel or wood construction in the marine field.

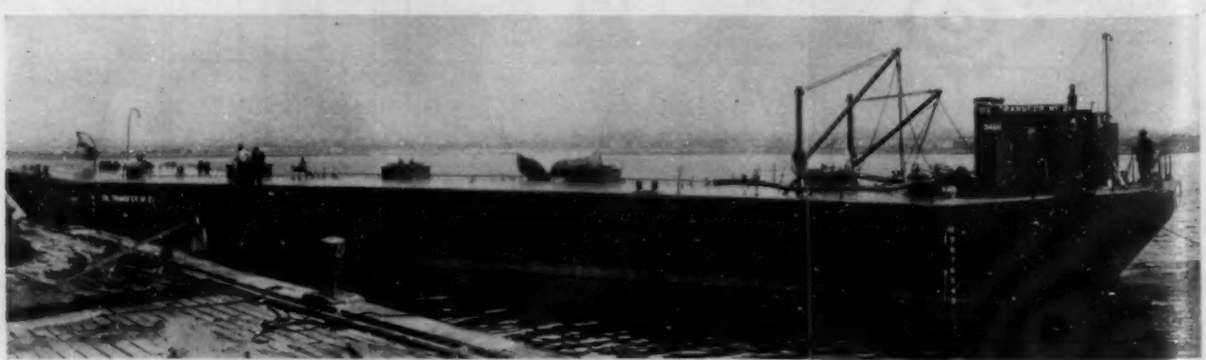


Fig. 10—10,000 Barrel Oil Barge

Welding on U. S. S. New Orleans

By CAPTAIN J. O. GAWNE

✦Paper to be presented at the Annual Meeting, American Welding Society, April 27th to 29th, 1932, New York, by J. O. Gawne, Captain (CC) U. S. N.

I. Introduction

THE RAPID increase in the use of arc welding in the construction of Naval vessels has been one of the most outstanding developments in recent shipbuilding practice. While, in new vessels, riveting is still used for connections of ballistic plating and main strength members, welding has replaced riveting in most of the other parts of the structure and in practically all fittings.

Before the World War fusion welding had only minor and sporadic application to Naval work. Acetylene was used to some extent in welding pipe, tanks and drums, and spot welding equipment was installed as early as 1912 at the Navy Yard, Puget Sound, and in 1914 at the New York Yard.

Fig. 1—U. S. S. *New Orleans*

The World War gave welding its first real start on Naval work. Some of the leading members of this Society took a prominent part in welding the damaged machinery of the interned German liners. The emergency of war demanded a quick and effective method of joining metals and means of securing water-tightness and oiltightness of compartments. In converting merchant ships to transports, welding was of special value and instances are recorded of welding stapling around frames to make non-watertight structure oiltight and of welding corroded rivets. All-welded battle towing targets were built at the Norfolk Yard in 1918. Welding was extensively used in the construction of the 157 foot seagoing tug *Pinola* at Puget Sound Navy Yard in 1919. The Mare Island Navy Yard welded a seaplane derrick barge in 1920.

The Washington Treaty of 1922 limiting Naval armaments gave welding its next real impetus. This Treaty placed a definite limit on the number and size of capital ships and aircraft carriers, and on the size of cruisers. Naval designers of the principal countries at once set to work to secure the maximum fighting qualities on the tonnage allowed. The two best methods of saving weight to devote to fighting qualities were the extensive use of arc welding and of light alloys.

The Bureau of Construction and Repair had begun an active study of the applications of arc welding in 1917. Since there were many new vessels of all types under construction after the War, opportunity was afforded for the application of welding in minor structures and fittings on battleships, destroyers and, to a greater extent, on the light cruisers of the *Omaha* class. With the signing of the Washington Treaty in 1922, this study assumed a new importance and many investigations were conducted at various Navy Yards, but principally at the Norfolk Navy Yard.

The *Salt Lake City* and *Pensacola*, the first two 10,000-ton cruisers built under the provisions of the Washington Treaty, were the first warships on which welding was applied to any considerable extent. It was used for some less important structural members and for a large number of fittings. The application of welding was progressively extended on the next six cruisers of the *Northampton* class and the two later vessels of the *Portland* group. This paper refers to the *New Orleans* class, which comprises the five latest vessels of the cruiser type.

A comparison of the working force employed on the *Pensacola* and four years later on the *New Orleans* gives a clear idea of the rapid strides which welding has made in Naval work in that short period.

This is the 22nd month in the 36-month construction period of the *New Orleans*. There are four gangs of riveters at work and 28 electric welders and the force is steadily being increased. In the corresponding month on the *Pensacola*, there were 14 gangs of riveters and 8 electric welders.

Throughout this paper the term "welding" will be used to refer to direct current metal arc welding unless gas welding is specifically mentioned. Gas welding is employed to some extent in shop work on piping and sheet metal but at the New York Navy Yard is little used in structural shop or on the ways except for aluminum.

II. Extent of Welding on the *New Orleans*

The *New Orleans* is one of fifteen 10,000-ton Treaty cruisers authorized by the Act of February 13, 1929. Under the London Treaty of 1930, but ten of these vessels can be built, the last three of the ten to be laid down one in 1933, one in 1934 and one in 1935. There are therefore seven of this authorization under construction at this time. The *New Orleans* is a vessel 588 feet long overall, 61 feet 9 inches beam, 21 feet 7 inches draft, 10,000 tons standard displacement, and mounts a battery of nine 8-inch guns in three triple turrets and eight 5-inch anti-aircraft guns. She carries seaplanes which are launched from catapults and picked up from the water (Fig. 1).

The extent to which welding is used is shown by the following details.

1. *Bulkheads.*—All the medium steel transverse and longitudinal bulkheads are entirely welded. This includes over 90% of the bulkheads on the ship and includes not only the main transverse and longitudinal structural bulkheads but also the bulkheads supporting turret foundations.

2. *Decks and Platforms.*—All medium steel plating and transverse beams connected to medium steel deck plating are welded. The transverse beams are generally built up of welded plates and shapes. In numerous cases, at the boundaries of special treatment steel portions of decks, the medium steel deck plating is joined to the special treatment deck plates by welded lap or butt strapped joints. Longitudinal beams are generally rolled sections and riveted, although about 30% of these beams are welded, generally at the ends be-

yond the middle half-length of the ship. All local stiffening of deck plating is obtained by flat bars with edge welded to the plating.

3. *Shell.*—The shell butts will be welded for the first 96 feet. About 80% of the length of the stem is built up and secured to the shell by welding. In earlier designs the stem was made up of steel castings.

4. *Inner Bottom.*—The two upper outboard strakes of plating of the inner bottom on each side are welded at the seams and butts, with single strap butt joints. This represents approximately 20% of the joints of the inner bottom.

5. *Longitudinals.*—The main strength longitudinals between the shell and inner bottom are riveted for about one half of their length amidships, as the shell plating in this area is riveted and it is desired to have these members work together. Toward the ends of

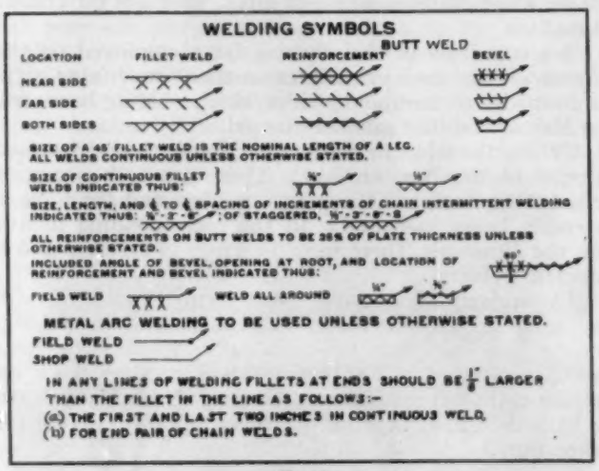

WELDING SYMBOLS
BUTT WELD
LOCATION
FILLET WELD
REINFORCEMENT
BEVEL
NEAR SIDE
FAR SIDE
BOTH SIDES
SIZE OF A 45° FILLET WELD IS THE NOMINAL LENGTH OF A LEG.
ALL WELDS CONTINUOUS UNLESS OTHERWISE STATED.
SIZE OF CONTINUOUS FILLET WELDS INDICATED THUS:
SIZE, LENGTH, AND ℄ TO ℄ SPACING OF INCREMENTS OF CHAIN INTERMITTENT WELDING INDICATED THUS:
ALL REINFORCEMENTS ON BUTT WELDS TO BE 25% OF PLATE THICKNESS UNLESS OTHERWISE STATED.
INCLUDED ANGLE OF BEVEL, OPENING AT ROOT, AND LOCATION OF REINFORCEMENT AND BEVEL INDICATED THUS:
FIELD WELD
WELD ALL AROUND
METAL ARC WELDING TO BE USED UNLESS OTHERWISE STATED.
FIELD WELD
SHOP WELD
IN ANY LINES OF WELDING FILLETS AT ENDS SHOULD BE ⅛" LARGER THAN THE FILLET IN THE LINE AS FOLLOWS:—
(a) THE FIRST AND LAST TWO INCHES IN CONTINUOUS WELD.
(b) FOR END PAIR OF CHAIN WELDS.

Fig. 2

the vessel the longitudinals taper down in depth to members known as stringers, which are welded. In addition there are welded stringers interposed between the extension of the longitudinals, some of them beginning 150 feet from the bow and stern to offer additional stiffness to the shell plates. The breast hooks, which are horizontal brackets at the bow, are entirely welded.

6. *Transverse Framing.*—In the way of the machinery spaces, the floors—deep transverse frames between inner bottom and shell plating—are riveted, excepting the oiltight and water-tight floors which have their connection to the shell welded. Beyond the machinery space, the floors and other transverse frames are riveted to special treatment steel shell plating and to the medium steel shell where the curvature of the shell plates produces too sharp a bevel with the transverse member to permit good welding conditions. In all other cases, floors and framing, especially at the ends, are made up of welded plates and are welded to the shell plating.

7. *Deck Erections.*—These structures are generally welded throughout with the exception of the special treatment steel portion.

8. *Foundations.*—Main engine and condenser foundations are generally riveted. Foundations for auxiliaries such as generators, pumps, oil heaters, auxiliary condensers, etc., are built up of welded plates and shapes. Catapult foundations, plate and stiffeners, are welded, with the exception of the top and bottom angle bar connections. Gun foundations for the anti-aircraft battery are specified to be welded, this being probably the first instance in which a gun foundation will be completely welded on any of our Naval vessels and probably on any Naval vessel. Extensive tests have been made at the Proving Grounds on welded gun foundations with successful results.

9. *Fittings.*—Fittings are generally designed for welding as it is on this type of work that the greatest percentage of saving in weight of individual members is realized. The following are instances of welded fittings: structural stanchions, awning and life line stanchions and their sockets, bitts, stowages and shelving—except aluminum portions—piping, hatch coaming and covers, door frames and doors, vertical ladders, minor foundations and supports, ventilation cowls and large structural vent ducts, ammunition hoist tubes, davits and davit fittings. Furniture, clothes lockers, etc., manufactured by the Norfolk Navy Yard of aluminum are joined mainly by spot welding.

10. *Auxiliaries.*—In the purchase of hull auxiliary machinery, preference has been given in the award of contracts to those who guarantee to furnish equipment of least weight as well as lowest cost. This obviously has required the manufacturers of auxiliaries to resort to the use of welding not only in their sub-bases and framing for the machinery but also in some of their working parts. Notable examples of the application of welding to auxiliaries are the steering gear and anchor windlass. Practically all of the sub-bases and bearing supports for this machinery are made up by welding.

Work under the cognizance of the Bureau of Engineering, such as main propulsion machinery, boilers and auxiliaries, are not included in this paper. However, a very important application of welding has been made in the steam and water drums of the boilers furnished by the Babcock and Wilcox Company. This work has already been described in a paper presented to the AMERICAN WELDING SOCIETY at the April, 1931, meeting. This Bureau is also requiring some of the sub-bases for auxiliaries, such as the generators to be made of built-up welded structures in lieu of heavy castings.

III. Design Features

Allowable Values of Stresses in Welds.—Test specimens made entirely of weld metal deposited with heavily covered fluxed electrodes recently delivered at the Navy Yard are giving ultimate tensile strengths of 70,000 lb. per square inch and elongations of 25%.

Test specimens of weld metal deposited with bare electrodes are giving ultimate tensile strengths of 60,000 lb. per square inch and elongations of 8 to 10%.

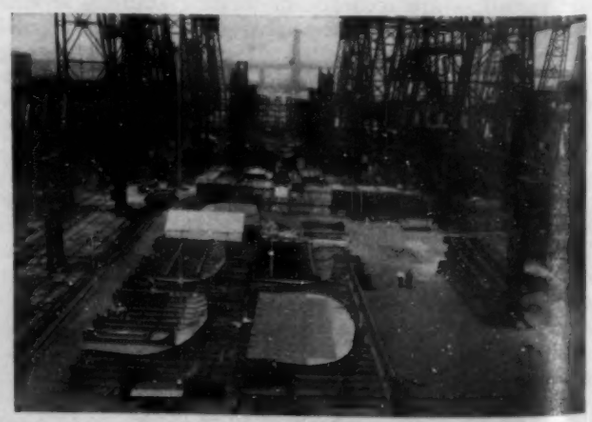


Fig. 3—U. S. S. *New Orleans* Bulkhead Assemblies in Field at Head of Building Ways

Before being allowed to work on Naval construction welders must pass a qualification test by welding three butt joints in medium steel plate, one in the flat, one in the vertical and one in the overhead position. The tensile strength of these joints must average 52,000 lb. per square inch and no one must be under 45,000 lb. per square inch. It is common to record values of 55,000 to 65,000 lb. per square inch on these tests and many of the specimens break in the base metal and not in the weld.

Notwithstanding the above values, ultimate stresses of 36,000 lb. per square inch in tension and compression and 29,000 lb. per square inch in shear are used as a basis for present design due to the lack of conclusive means of testing on shipboard and the resulting uncertainty as to the quality of the weld. This uncertainty is based on:

1. The so-called "human elements," which influences the uniformity of workmanship.
2. The condition of the base metal after the joint is made in a ship-shaped body in which the component parts are more or less rigidly connected, with the possibility that locked up stresses of unknown magnitude may be present.

Since a qualified welder must demonstrate his ability to make welded butt joints that will average 52,000 lb. per square inch, it is evident that a factor of safety of 1.44 is used to allow for the uncertainty mentioned above. The minimum strength of base metal for the medium steel used for ship work is 60,000 lb. per square inch in tension and 48,000 lb. per square inch in shear.

Other values considered in the design of ship structure are given in the 1931 edition of the Navy Welding Specifications.

These values are based on bare metal electrodes. While it is not believed that any change will be made for the present in the basic design value of 36,000 lb. per square inch, there are indications that improvements in welding equipment will justify an increase. The excellent results being realized with heavily covered fluxed electrodes support this belief.

For working stresses, the allowable values of 36,000 lb. per square inch and 29,000 lb. per square inch are divided by a factor of safety of 4 giving values of 9000 lb. per square inch in tension and compression and 7250 lb. per square inch in shear. Since tests point to a safe fatigue limit of 10,000 lb. per square inch for welded material, this working stress is not too low. For structures subject to impact, a factor of safety of 12 seems reasonable.

Fig. 4—Built-Up Tee-Bar Stiffeners

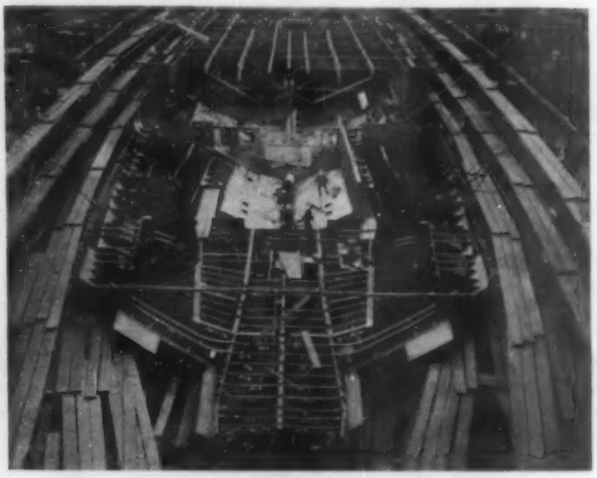


Fig. 5—Welded Transverse Framing

In adopting welding for ship's structures, the general procedure has been to compare the strength of the welded connection to the strength of the riveted joint that would have been used with riveted construction. This was followed because of the indeterminate character of the stresses to which a ship's structure is subjected and because it was the simplest method of changing over to welded construction. It was soon noted that a stronger connection could generally be made with welding as the welding material can be placed to any spacing or made continuous whereas the riveting specifications set a minimum limit to rivet spacing in single or multiple rows. Thus, with welding a greater load could be transmitted per unit area of plate or shape than with riveting. This fact, it is noted, has been used to advantage in building structures on shore, resulting in a minimum number if not the complete elimination, of gusset places.

Welding Symbols.—There is printed on each plan for the construction of the cruisers a table of welding symbols, as shown on Fig. 2. This is being done to accustom draftsmen, shipfitters, welders and other workmen to the meaning of the symbols and to encourage their use to facilitate drafting work and reading of plans. The symbols are, in general, similar to those adopted by the AMERICAN WELDING SOCIETY. It might be added that only in rare cases is hatching used along a structural division line or joint to designate the weld. All symbols are placed under a short horizontal line—or butt weld symbol as shown—and an arrow connects this line to the connection which the symbol describes.

Bulkhead Design.—Figure 3 shows an assembly of main transverse bulkheads as used on this ship. The welded bulkhead was adopted after numerous tests made at the Norfolk Navy Yard in 1929 on large bulkheads 12 ft. x 12 ft. of both riveted and welded designs. The important feature of the welded bulkhead is the absence of the entire bounding angle bar connecting the bulkhead plating to the inner bottom plating, as used in the case of the rivet bulkhead. Also the welded bulkhead saves the weight of the stiffener flanges which are necessary for connecting the stiffener to the plating in the case of the riveted bulkhead.

Aside from the saving in weight and cost of the raw material of the bounding bar, there is a large saving in cost of labor in joggling and stapling the bar over plate laps in the inner bottom, over corner longitudinal bars, and around beams passing through the bulkhead. On ships, the smith work of stapling angle bars or shapes

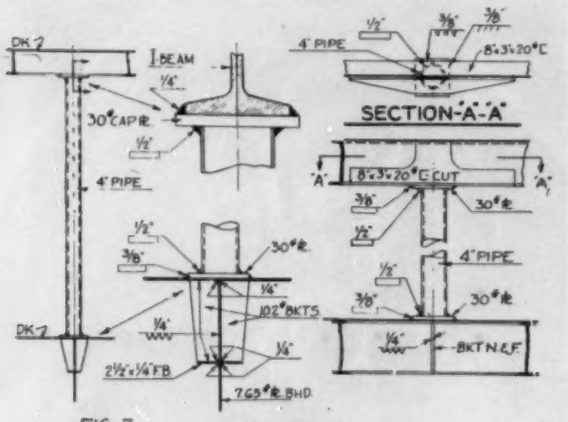


FIG. 7 STANCHIONS

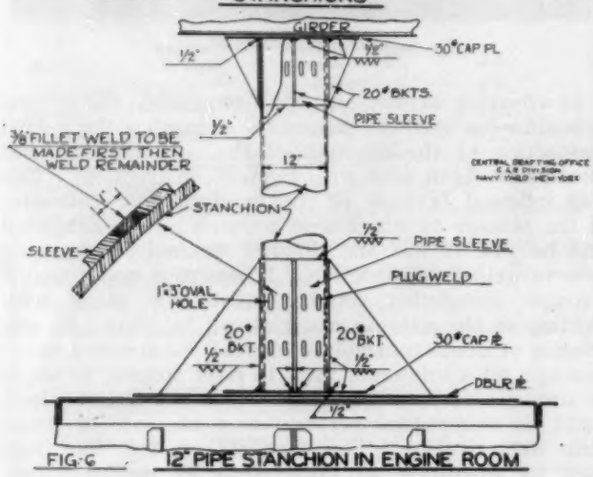


FIG. 6 12" PIPE STANCHION IN ENGINE ROOM

around other bars and plate laps has always been a costly job. The omission of bounding bars also saves the use, in many instances, of canvas stop-waters or oil-stops. Around the deck beams, plate collars burned to the beam contour are welded to the beam and to the bulkhead plating for water-tightness.

A very important feature of the welded bulkhead shown is the design of built-up tee-bar stiffener, as shown in more detail in Fig. 4. This consists of a plate web and face plate welded together before securing the stiffener as a whole to the bulkhead. The advantage of this type of stiffener is that only the material required for strength is used. This material is placed and proportioned to meet the stresses which the stiffener must withstand and every pound of weight is effective. The brackets at top and bottom are formed by knuckling the face plate and burning the web plate to the desired contour. The welded stiffener shown in Fig. 4 is 20% lighter than a corresponding riveted stiffener.

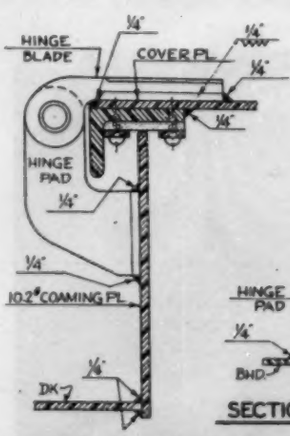
Shell Plating.—The shell plating at the forward end of the vessel has the butts of the plating welded with single-strapped butt joints. The seams are single-strapped, riveted joints below the waterline and riveted, lapped joints above. Welding is not used for the seams of the plating. Full scale tensile tests on plating made by the Bureau of Construction and Repair in the laboratories of the Bureau of Standards have not been sufficiently satisfactory. The transverse web framing is welded to the shell as well as to the stringers, decks and breast hooks. The absence of bounding angle bars between these members and the shell plating is a saving in weight which can be realized. The procedure in welding the forward structure has been the subject of considerable discussion due to the differences of opinion as to the sequence of welding the various structural members to avoid locked-up stresses and yet not depart in the direction of higher costs from the usual shipbuilding methods of construction and assembly. The procedure finally adopted will be described in the section on "Installation on Ship."

Transverse Framing—Outside of Double Bottom Area.—Figure 5 shows a portion of the welded transverse framing in the after part of the vessel during the early stages of construction. This framing is considerably simpler than the riveted type with its complicated connections.

Fittings.—Figures 6 and 7 show the details of large and small welded stanchions. On previous cruisers, the small stanchion shown in Fig. 7 was made up with a tee-bar head and foot in lieu of the flat plate as shown. The web of the tee-bar was fitted into a vertical slot cut in the pipe and the ends of the pipe landed on the top side of the flange. The flanges were then either riveted or welded to the deck beams. The stanchions as shown in both Fig. 6 and Fig. 7 are not only lighter than the old design of stanchion with forged head and foot, but also less costly due to the simplicity of their parts and the elimination of the expensive forging and machine work for the ends of the stanchions.

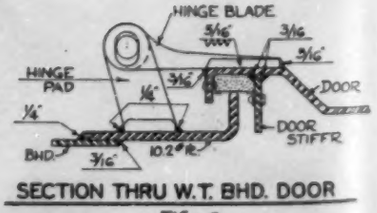
Figure 8 shows a section through a welded hatch coaming and cover. The coaming is welded to the deck as shown or it may land on the deck plating sufficiently back so that the deck plate forms a ledge for a hatch grating. The hinge pads are welded to the coaming and hatch cover as are also the lugs for the drop bolts. The drop bolts are hinged to U-shaped pieces welded to the coaming plate. Figure 9 shows a section through a welded water-tight door frame. The door frames are welded to the bulkhead plating. The other fittings welded in addition to the hinge pads and the stiffening ring in way of the rubber gasket are the wedges for the dogs which are now made of steel and welded to the door plate and the bearing fitting for the dog spindle. This has eliminated numerous composition castings from the door. A brass composition is brazed or welded to the steel dog to act as a wearing piece when rubbing over the welded steel wedges.

There are many other applications to hull fittings which might be shown if time permitted, such as welded butts, welded life-line and awning stanchion sockets, welding of all fittings to life-line and awning stanchions,



SECTION THRU COAMING OF HATCHES & MANHOLES

FIG. 8

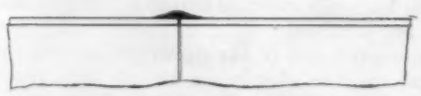


SECTION THRU W.T. BHD. DOOR

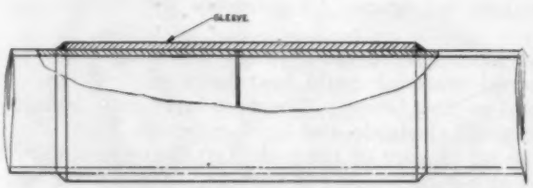
FIG. 9

thus eliminating heavy composition castings, welded steel lockers, stowages and minor foundations. In some fittings, the saving in weight amounts to over 50%. For example, in the case of the awning stanchion sockets, which were previously made of brass castings and riveted in the waterways at the ship's side, the weight of each casting was about 64 lb., whereas the welded steel pipe and plate fitting developed to replace the brass casting weighs about 17–18 lb. Stowages, minor foundations and mechanical fittings offer the greatest opportunities for saving in weight by the use of welding.

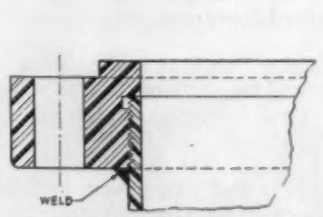
The replacement of numerous heavy brass castings, which cannot be cast in steel due to the small wall thicknesses, by welded steel plate, shapes or pipe makes for a saving in weight due to the difference in specific gravity of the material as well as to the greater strength of the steel, which permits lighter scantlings. Even when steel castings are replaced by welding, a large saving is realized due to the elimination of surplus thickness in the steel castings, which is necessary in order to produce sound castings. In either case, the simplification permitted by the use of welding results in a saving in weight.



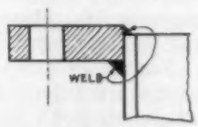
TYPICAL SADDLE OR BEAD WELD
FIG. 10



TYPICAL SLEEVE TYPE JOINT
FIG. 11



TYPICAL FLANGE AS FITTED H.P. HYDRAULIC PIPING
FIG. 12



TYPICAL FLANGE FOR L.P. PIPING
FIG. 13

CENTRAL DRAFTING OFFICE
C & R DIVISION
NAVY YARD, N.Y.

It is in work of this kind that welding is of great value in warship construction. It simplifies design work, saves weight and saves time and labor in installation.

Piping.—The piping discussed in this paper is the hull piping, under the cognizance of the Bureau of Construction and Repair and comprises ship's service piping as distinguished from piping connected with the main propulsion machinery and its auxiliaries under cognizance of the Bureau of Engineering. The Hull piping includes the following.

1. Standard wrought iron pipe for fire and flushing systems—working pressure fire 100 lb., flushing 30 lb. per square inch.
2. Seamless steel tubing for bilge drainage—working pressure maximum approximately 15 lb.
3. Lapwelded steel casing for fuel oil filling and overflow piping and sounding tubes—filling working pressure approximately 22 lb. Overflows and sounding tubes, working pressure variable approximately 0 to 15 lb.
4. Standard steel pipe for air escapes—working pressure approximately 15 lb. maximum.
5. Seamless steel tubing for hydraulic power units such as steering gear and windlass, boat and airplane cranes. Working pressures up to approximately 900 lb. per square inch.

Brass and copper tubing are used for certain systems such as gasoline, fresh water and certain low pressure compressed air systems. Where such tubing is used with flanges, the latter are brazed on the tubing.

It will be noted that all of the above piping except the hydraulic piping, item 5, are subject to working pressures of 100 lb. or less.

Welding is used generally for making joints in all wrought iron and steel piping. In many cases the ends of sections of pipe are simply butt welded to each other. In cases where a portable section of pipe is desirable, flanges are welded to the ends of the pipe and secured together with bolts.

At the New York Yard arc welding is used in the pipe shop to a far greater extent than gas. At the Philadelphia Yard, on the contrary, practically all welding in the pipe shop is done with gas.

In the installation of piping on the vessel, the general practice is to use only arc welding. Arc welding permits the welder to use longer leads, makes it easier for him to move about on the ship, and is handier and safer for work in confined spaces and awkward positions for the welder, such as are frequently encountered in compartments aboard ship.

Line joints are made up with square butt or sleeve joints. The square butt joint is connected by a square butt weld or a saddle weld, as shown in Fig. 10, also referred to as a bead weld. A typical sleeve joint is shown in Fig. 11. These types of welds are used since—

1. The piping has a wall thickness of $^{3}/_{16}$ in. and less, being in certain cases as low as 0.09 in. Either arc or gas weld can penetrate the joint at these thicknesses.
2. With either the square butt or the sleeve joint there is less likelihood of producing "icicles" inside the pipe than with a vee-weld. Icicles are objectionable especially in certain systems such as the drainage lines where the projection may collect bilge refuse and clog the pipe.

Flanged joints are used where it is necessary to have removable sections of pipe. The flanges are welded to the pipe as shown in Figs. 12 and 13. Fittings such as tees, Y's and crosses are dispensed with and the branches are welded directly to the main. The saddle joint is used in such cases without expanding the end of the branch, bell-fashion, where the branch joins the main.

For elbows, the plans permit the option of using any of the following types:

1. Elbows made from pressed plate and joined by welding, with the seams in a plane passing through the center of the bend.
2. Elbows manufactured by processes which retain constant wall thicknesses throughout the bend.
3. Elbows built up of mitered sections of pipe of the same size as the straight lengths using 4 or 5 segments for a 90° bend.

Pipes piercing ship's structure are secured to the structure for support and tightness by the various

methods indicated in Figs. 14 to 19. Where space is limited the type shown in Fig. 14 is used. This type involves making one of the flange welds a field weld with possibility of leaks at the flange which is likely to be subjected to greater pressures than would ever occur at the bulkhead weld. Figure 15 is preferable if space permits as the fitting can be made up and tested in the shop before installation, and also permits greater accuracy in fitting the flange. The method shown in Fig. 16 is used in way of decks covered with wood planking or tile and insulated bulkheads. Figure 16 with modifications shown and Fig. 17 indicate the method that is used for piping that is to be insulated from the structure to minimize electrolytic action. Brass or copper pipes piercing structure are secured to the structure by welding to steel sleeves that have been brazed on the pipe in the manner indicated in Figs. 18 and 19.

Built-up welded sections of piping with bends or offsets and outlets such as Fig. 20 are fabricated in the shop from detail plans for each piece.

IV. Materials

In the construction of this cruiser, welding is applied to the following materials: Medium steel; special treatment steel; cast steel; cast aluminum alloys; rolled aluminum alloys; and steel and wrought iron pipe.

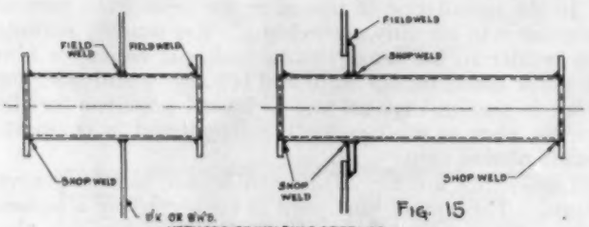
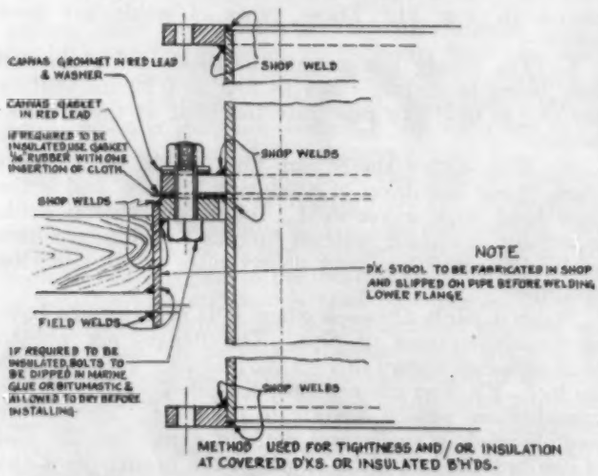


Fig. 14 — Fig. 15

METHODS OF WELDING STEEL OR WROUGHT IRON PIPING AT D'KS. OR B'H'DS


CANVAS GROMMET IN RED LEAD & WASHER
CANVAS GASKET IN RED LEAD
IF REQUIRED TO BE INSULATED USE GASKET 1/16" RUBBER WITH ONE INSERTION OF CLOTH.
SHOP WELD
SHOP WELDS
SHOP WELDS
NOTE
D'K. STOOL TO BE FABRICATED IN SHOP AND SLIPPED ON PIPE BEFORE WELDING LOWER FLANGE
FIELD WELDS
IF REQUIRED TO BE INSULATED, BOLTS TO BE DIPPED IN MARINE GLUE OR BITUMASTIC & ALLOWED TO DRY BEFORE INSTALLING.
SHOP WELDS

METHOD USED FOR TIGHTNESS AND/OR INSULATION AT COVERED D'KS. OR INSULATED B'H'DS.

Fig. 16

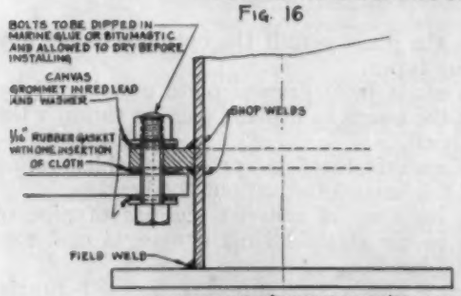
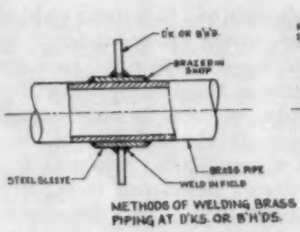

BOLTS TO BE DIPPED IN MARINE GLUE OR BITUMASTIC AND ALLOWED TO DRY BEFORE INSTALLING
CANVAS GROMMET IN RED LEAD AND WASHER
1/16" RUBBER GASKET WITH ONE INSERTION OF CLOTH
SHOP WELDS
FIELD WELD

Fig. 17 — METHOD USED FOR TIGHTNESS AND/OR INSULATION AT NON-COVERED D'KS. OR B'H'DS.



METHODS OF WELDING BRASS PIPING AT D'KS. OR B'H'DS.

Fig. 18

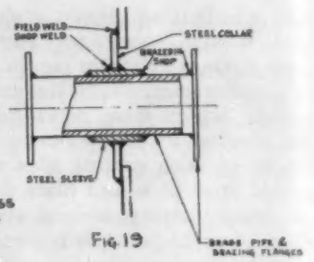


Fig. 19

Medium Steel.—The greater part of the hull structure and fittings is composed of medium steel. Navy specifications for this material require a minimum tensile strength of 60,000 lb. per square inch, a minimum elongation of 25% and a transverse cold bend of 180° to a diameter of one thickness. The only chemical requirements are that phosphorus shall be below 0.04% and sulphur below 0.05%. However, steel of these physical characteristics will generally have a carbon content ranging from 0.20 to 0.30%. This material is welded with both bare and heavily covered fluxed electrodes and excellent results are attained.

Because of the importance of saving weight due to the limitation placed on the displacement of this vessel by the Washington treaty, scantlings are made as light as is consistent with safety and good design practice. Loss of section by corrosion of the lower interior structure is guarded against by extensive use of galvanized steel.

Experiments were made which indicated that this galvanized material could best be welded by making the weld in two layers. The first layer was deposited with a small electrode and light current. This burned the zinc off in way of the weld but the resultant weld contained a good many gas pockets. The second layer was deposited with a standard size electrode and corresponding current. This weld gave the cross section necessary for strength and fused out the gas pockets in the primary bead.

Special Treatment Steel.—The next largest item is the special treatment steel used for parts of the hull structure where strength is of vital importance, for protective plating on decks and bulkheads, and for the armor belt. This is an alloy steel of 120,000 lb. per square inch minimum tensile strength, and elongation in 2 in. of 19%. Plates are subjected to physical and ballistic tests but no chemical requirements are specified.

No welding is done on special treatment steel where strength is of importance. In a few cases the bottom boundaries of light partition bulkheads are secured by welding to special treatment decks. Where it has been necessary to weld to this class of steel better results have been attained with heavily covered fluxed electrodes.

Steel Castings.—Some welding has been performed on steel castings, primarily to correct minor defects. When any considerable amount of welding has been done, castings have been re-annealed to relieve shrinkage strains.

Aluminum Alloys.—Because of the importance of saving weight on these vessels a large amount of aluminum alloy is being used. Castings of both silicon-aluminum and aluminum copper are used. Wrought aluminum alloys of aluminum and manganese, or aluminum copper, magnesium and manganese are used. Welding on these materials is limited primarily to repairing

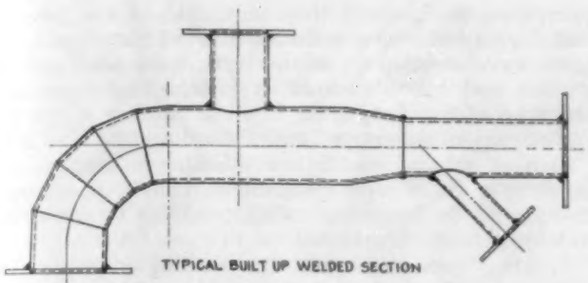


FIG. 20

defects or making alterations. Experience at this Yard has been that the arc fuses aluminum so rapidly that the material tends to break down in way of the arc and forms holes. When necessary to weld aluminum a light weight oxyacetylene torch of the type known as an aircraft welding torch has been used. Results obtained by this method are satisfactory except for some warping.

Welding Electrodes.—For some years it was the belief in many Navy Yards that the welding profession threw an unnecessary air of mystery around the extraordinary virtues of certain special electrodes and that any electrode which met the Navy Specifications which defines the maximum carbon, manganese, phosphorus and sulphur would be satisfactory for production work. However, some of the more persistent manufacturers succeeding in getting their special rods tested and the results were such that the specifications for welding electrodes are now being revised to permit purchase on the basis of a work value and a factor of merit. That is, for each rod submitted for test, weighted values will be assigned for tensile strength, ductility, speed of deposition, penetration, etc.; on the basis of these results a "work value" will be assigned. This work value divided by the price per pound will give the factor of merit and the electrode having the highest factor of merit will be purchased.

These revised specifications will divide electrodes into four groups:

1. Bare steel electrodes.
2. Covered steel electrodes.
3. Electrodes for depositing wearing surfaces.
4. Gas welding wire of bare iron and steel.

Of these four classes of electrodes two are being extensively used in the construction of the *New Orleans*, i.e., the bare electrodes and the covered electrodes.

The Yard has been able to secure bare electrodes giving an average tensile strength of 60,000 lb. per square inch in all positions with minimum elongation of 10% in 2 in. These results are from specimens of all weld metal cut from the length of a vee joint.

Heavily Covered Fluxed Electrodes.—Heavily covered fluxed electrodes have been obtained which gave an average tensile strength above 70,000 lb. per square inch in all positions with a minimum elongation above 20% in 2 inches.

Because of results on laboratory test and in actual use it has been decided to use heavily covered fluxed electrodes on all work in the flat position.

Bare electrodes will be used for tacking for welding in the vertical and overhead positions and for work where low cost and ease of handling by all operators are more important than strength and ductility.

In addition to high strength and ductility, the heavily covered fluxed electrode seems to produce a weld of higher specific gravity with relatively few gas pockets. However, even the most skillful welders require careful training before they can avoid undercutting and can produce a satisfactory weld, even in the flat position. Further training and experience in handling the wire seems to be necessary before satisfactory welds can be made in the vertical and overhead positions.

V. Plant Layout for Welding and Equipment in Use

Plant Layout.—In the selection of welding equipment to be purchased, considerable thought has had to be given to the layout of the yard distribution system from which the primary current for driving the welding generators is secured.

The main feeder lines for the piers and drydocks throughout the Yard, which were installed many years ago, are 220 volts, direct current. The feeder lines for the shipbuilding ways, which were installed in 1918, are 220 volts, alternating current. Therefore both direct and alternating current driven equipment has to be provided.

Welding Machines.—The Yard would prefer to buy only the alternating current driven welding equipment because of the slightly lower first cost and the considerably lower maintenance cost. The alternating current driving motors give little or no trouble, while the hard service to which they are subjected frequently causes sparking and commutation troubles in the direct current motors.

An excellent idea of the rapid growth in the use of welding on Naval work may be gained from the fact that at the peak load near the end of the World War on November 1, 1918, there were 17,189 men on the payroll and welding machines to supply 5 operators. Ten years later, on November 1, 1928, there were 3568 men on the payroll and welding machines to supply 41 operators. Today there are 3886 men on the payroll and welding machines to supply 84 operators. The Yard has requested for immediate use machines to supply 53 additional operators, making a total of 137.

The welding equipment now on hand for supplying 84 operators consists of a variety of machines purchased from different manufacturers, usually from the low bidder, at intervals from 1919 to the present time. Last year there were installed at the building ways for the construction of the *New Orleans* 3 constant potential 8-operator sets. The motor and generator for these sets were placed under cover on solid foundations on the ground, one forward, one amidships, and one aft. The resistor panels for controlling the individual operators' currents were housed in the staging at the main deck level. This permits the operator to come down one step from the main deck level to the staging to adjust his current values. It has been found that

Fig. 21—Shop Welding Slab—Channel Frame Unit Bracket

the welder is more likely to adjust his current to the best value for the work when he does not have to climb down from the main deck to the ground some 40 feet or more and back every time he should change the setting. These machines have given very satisfactory service so far. However, the recent increase in the use of heavily covered fluxed electrodes with reversed polarity makes it desirable for an individual operator to be able to reverse polarity at will, when he shifts from bare to covered electrodes. It is more convenient for an operator to reverse an individual machine.

Accessories.—Suction blowers are kept on hand at convenient locations in the staging alongside the ship and a 4-in. lead of flexible metallic hose is taken to any point where a welder must work in a confined space or weld galvanized material below decks. This has been found more satisfactory than a supply from an air hose and results in much better production when the welder must work under such conditions.

Some difficulty has been experienced in getting satisfactory helmets and hand shields to protect the welder's eyes from the glare of the arc. Some of the helmets and shields which have passed the test of Navy Specifications have developed serious light leaks through the corners and seams because of knocks in service and shrinkage of the fiber.

Each welder is equipped with the following:

Helmet or hand shield; heavy leather gloves; canvas armlets; a set of gages to check weld sizes; wire brush and scraper for removing scale; respirator for use when welding galvanized material.

Welding supervisors and the welding inspector are each equipped with a set of gages to check weld sizes, with polarity indicators, with magnifying glasses and with good flashlights to search for cracks in finished work.

A recording ammeter and voltmeter reading up to 400 amp. and varying in speed from 1 in. per minute to 1 in. per hour has been purchased and is used to secure data on current values being used for different classes of work.

Fig. 22—(Upper) Setup for Welding Stem on U. S. S. *New Orleans*

Fig. 23—(Middle) Welding Distance Pieces to the Pipe—Built-Up Stem

Fig. 24—(Lower) Final Assembly of Stem in Shop

VI. Organization for Welding

Welding on hull construction at the New York Yard is under the immediate direction of the New Work Superintendent.

He exercises executive control of welding personnel through the organization of the shipfitters' shop. All hull structural trades including welders are grouped together in one shop under a master mechanic known as the Master Shipfitter. The Master Shipfitter issues his orders to supervising welders whose duty it is to:

1. Consult freely with supervising shipfitters and supervisors of other trades involving welding to have a general idea of their needs so that he can plan his work to have personnel and machines available to meet those needs.
2. Lay out each day's work for each welder, see that it is planned and carried out in the most efficient manner and that workmanship and output are satisfactory.
3. Examine work to which he assigns welders to see that it is properly prepared for welding.
4. Be familiar with plans to see that all work is performed exactly as specified by plan.
5. Check all equipment used by his men from the control panel to the electrode to see that it is suitable for the job and functioning properly.
6. See that all safety rules and regulations are carried out and that the safety of each of his men is provided for, particularly those working in tanks or badly ventilated spaces. He shall particularly see that proper light and air are provided for each welder.
7. Check the daily report cards of welding to follow up the daily production of his men.

The New Work Superintendent is assisted in details of welding policy by the welding engineer, who acts in an advisory capacity as a consulting engineer on all matters pertaining to welding from the start of plans in the drafting room to the final completion and inspection of the welding performed in the ship.

The welding engineer has executive control of and responsibility for:

1. The provision of all welding equipment and accessories.
2. The selection, training and qualification of welders.
3. The welding school.
4. The inspection of all welding in the shops and on ships under construction.
5. Comprehensive program for development.

Hiring and Qualification of Welders.—The supply of welders is drawn either from a list of qualified applicants at the employment office or from graduates of a welding school operated by the Navy Yard.

When a welder is hired through the employment office he is first sent to the welding school and given the Navy standard qualification test in flat, vertical and overhead positions. If he cannot pass this test he is not employed. If he qualifies he is kept in the welding school for three days to become familiar with methods and with standards of workmanship which will be required of him. This has been found desirable regardless of how excellent his previous training or how great his experience.

All welders, regardless of how long they have been employed, are given qualification tests semi-annually. When a man fails to pass this test he is sent back to the welding school for training to eliminate his weakness. It is usually found that in a short time he can be trained to meet the requirements.

Welding School.—The Navy Yard operates a welding school to train its own men to meet the need for an increasing force of welders. It has been found that a carefully selected ambitious helper in the metal trades can be trained in the school to become a more valuable and dependable welder than the average welder hired from the open labor market. These boys are sent to the school two hours a day for six months. In addition lectures are given each week and work is assigned for home study from welding text-books. On completion of this six months of instruction they are given a week of intensive training eight hours a day. They are then given the Navy standard qualification test. When they pass this test they are sent out as helper welders to do tack welding for shipfitters assembling structure and to weld on less important work where life and safety are not involved.

After two years as helper welders, they are, if qualified, promoted to third class welders.

VII. Layout in Mold Loft and Manufacture in Shops

Laying Out Work in the Mold Loft.—In shipbuilding it is the practice to send the plans of the hull structure from the drawing room to the mold loft, where the lines of the ship are laid off full scale on the mold loft floor and full size molds or templates of wood or paper are made of each individual piece.

These molds are then sent to the structural shop where the steel is laid off, shaped and has the various operations performed on it as indicated on the templates.

The biggest change in mold loft work caused by the extensive use of arc welding is the elimination of holes. Where a large shell or deck plate formerly had 700 or 800 holes, a plate to be welded will have perhaps 3 holes on each of the four edges for holding it in place when erected.

Another change in the mold loft work has been caused by the introduction of built-up stiffeners and girders welded together out of pieces of plate instead of using the conventional rolled sections. In laying out a channel stiffener, a loftsman formerly made only one mold to show the holes in the faying flange. With the built-up stiffener he must make one mold for the web plate and another for the face plate which welds to it. This consumes some of the money which has been saved by not having to lay out rivet holes.

The loftsman, like all other structural trades, must be more accurate in his work on all-welded construction to get a more exact fit between parts of the structure because holes are not available to permit the erectors to readily draw members up with bolts to a snug metal-to-metal fit.

While fairly accurate data are available as to shrinkage which may be expected in all welded construction, it does not appear desirable at this time to attempt to make any shrinkage allowance in the mold loft such as is made in the pattern shop for the shrinkage of a casting.

Manufacture in Structural Shop.—When the completed molds reach the structural shop, the raw material is brought in and the first step is to lay off the steel from the templates. A structural shop for shipbuilding is usually divided into two bays, one for plates and the other for angles or shapes. Let us consider the plate bay first. This laying out is much simpler for all-welded construction than for a riveted job because there are only a few holes to be marked and center punched on each piece instead of a large number, possibly even several hundred.

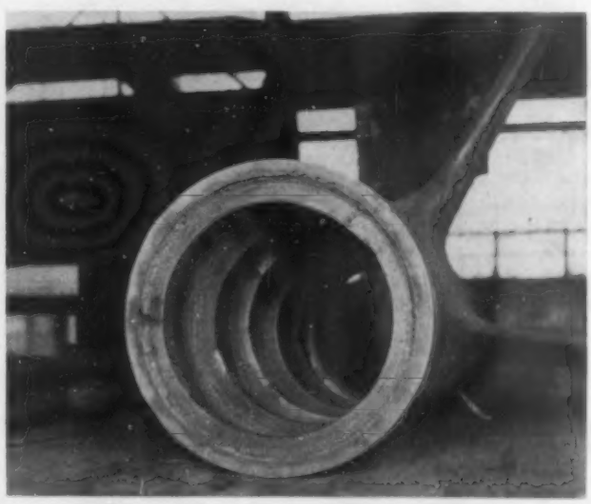


Fig. 25—Welded Bearing Rings in Shaft Strut

In the progress of the material through the shop all the conventional operations for holes are practically eliminated. Where a riveted job would require punching, drilling, reaming and countersinking, a welded job would require only the punching of a very few holes for erection purposes.

In shaping plates, either in the furnace or in the bending rolls, greater care and more accurate workmanship are necessary in welded ship construction. In riveted work, there are many holes which afford a ready means of pulling plates up to frames, beams, butt and seam straps. But with welded design, the plate must be accurately shaped when it leaves the shop or much time and money will be expended in getting metal-to-metal contact.

To reduce the number of butts in plating and the shrinkage which each butt involves, the tendency is to get plates as long as possible. This is desirable on straight work, but where much shape is involved it will be found much handier and more economical to limit the plates to a size that can be conveniently handled in rolls or furnace.

In the angle bay of the shop it will be found that many of the above remarks on plates apply equally to shapes. This is true of the simplification of layout; the elimination of punching, drilling, reaming and

countersinking; and the greater care required in shaping. One great change in the angle bay is the substitution of built-up plate girders and stiffeners for the customary rolled shapes.

A built-up plate stiffener or girder requires more care in laying out and more work in assembling for welding than is necessary in punching the faying flange of a channel or I-beam. But the weight of the faying flange is eliminated and the face plate can be proportioned to the work which it must do.

Another change which affects the angle bay of the shop is the replacement of forged welded corners with arc welded corners.

Sub-Assembly in the Shop.—It is very desirable to do the maximum amount of sub-assembly and welding in the shop. By proper design and planning nearly all of the welding can be done in the down position. Furthermore, the assembly can be done in the shop rather than in place on the ship, which affords the workman favorable conditions of weather and light and which permits him to send to a nearby tool shop for alteration any part which does not fit properly.

An ordinary ship bending slab has been found to be almost ideal for sub-assembly and welding of built-up parts. In fact, it has proved so satisfactory that a special slab has been cast and installed in the shop and is known as the "welding slab" (Fig. 21). Dogs such as are used to hold angles for bending are found to be a very cheap and effective method for holding built-up parts for welding.

Manufacturing a Welded Bulkhead.—All the main bulkheads of the *New Orleans* are of all-welded construction with built-up stiffeners.

The first step for plates is to be laid out from template. The next step is to shear the plates to size. From the shears, the plates go to the joggling machine. Most of the joints on the bulkheads are joggled laps. These seem to be a very practical design, both because they are better than butt welds for shrinkage and because any little irregularity in the size or fit of the plates simply increases or decreases the width of the overlap. After being joggled, the plates are weighed and then go to the skids for sub-assembly.

The built-up stiffeners, like the plates, start by being laid out from mold. The webs and face plates are then burned and sheared to size. These pieces of plate, cut to size, are next sent to the welding slab. They are fitted together by the shipfitter, tacked into place and then finish welded.

In welding these stiffeners there was a considerable tendency for the welding to shrink the welded edge. This was overcome by dogging the parts firmly in place, tack-welding at intervals along the length, and "finish" welding by the so-called "wandering method" of welding 3 in. and skipping 18 in. so as to avoid too great a concentration of heat in any one locality.

It is believed that economy could be effected by training the shipfitter or other mechanic making the assembly to do enough welding to tack together the work which he is assembling. Then small work would require only one man, working continuously, until it was ready for finish welding. When these stiffeners are finish welded, they are sent to the assembly skids to be welded to plating.

The plates are first spread out in their proper locations. The water lines or reference lines and the location lines for stiffeners are then struck in with chalk lines. The distance between adjacent water lines are then checked to make sure that the heights are correct and the bulkhead square. The plates are then tack-welded along the seams and butts, which are usually joggled lap joints. The stiffeners are put into place, squared and tack-welded, so that the water lines, or reference lines, on the stiffeners agree with the water lines on the plates.

The next step is to put ribbands or heavy wood braces across the stiffeners to hold them in shape. In case of very large bulkheads, it is usually desirable to put channel braces near each edge to insure keeping the bulkhead in alignment.

The bulkhead is now ready for "finish" welding. It has been found best to start at the center of the bulkhead and work outward along a seam toward each end. The welder would start at the centerline, work about 6 in. to the right. Then he would return to the centerline and work about 6 in. to the left. Next, he would add 6 in. more to the right and then 6 in. to the left alternately until the seam is completed.

Next, the butts were welded, starting at the center of the joint and working outward toward the ends. Finally, the stiffeners were welded to the plating, starting with the stiffener nearest the centerline and welding alternate stiffeners on each side of the centerline out to the sides. Each individual stiffener was started at its center and worked out to the end. This was "intermittent chain welding" and corresponding increments on both sides of a stiffener were welded in sequence. At the ends, in way of the brackets, the stiffeners were attached to the plating by continuous welds which were made by the stepback method.

The bulkhead was next turned over and seams and butts of plating were welded on the opposite side. The bulkhead was then placed in the ship by the crane, shored in position, tacked and finally "finish" welded. No difficulty was experienced in welding these bulkheads after the above procedure was established. However, it is not believed that even the strongest advocate of welding would claim that it will make fair and straight plates which are received on the welding slab in a wavy or slightly buckled condition. Many plates for the *New Orleans* were received from the mills in such condition and welding naturally did not improve them. The practice was therefore established of running these wavy or warped plates through the straightening rolls before assembling.

In comparing one of the main machinery bulkheads which were welded on the *New Orleans* with a corresponding riveted bulkhead on the preceding cruiser built at this Yard, the *Pensacola*, it is very evident that the welded job requires fewer men but more time. The riveted job requires shipfitters to assemble; drillers to ream, countersink and bolt up; a gang of riveters to drive, and chippers and caulkers to trim and caulk for tightness. A welded bulkhead requires only the shipfitter and a welder but they would require two to three weeks as compared to four or five days for all trades on a riveted bulkhead.

The Built-Up Stem.—A decided innovation in welding on this vessel is the built-up stem consisting of a double extra strong pipe with plates welded to it to replace the customary stem castings. The lower section where the keel turns upward to the stem is, as usual, of cast steel and the extreme upper four feet is a casting but the intermediate $40\frac{1}{2}$ feet are entirely welded.

The first step in building the welded stem in the shop was to make a form of a plate and two angles to the shape of the outer edge of the stem (Fig. 22).

The pipe was then shaped and laid in this form, tack-welded to it and checked for straightness. A compressed air hose was connected to one end of the pipe and allowed to blow through to carry away the heat of

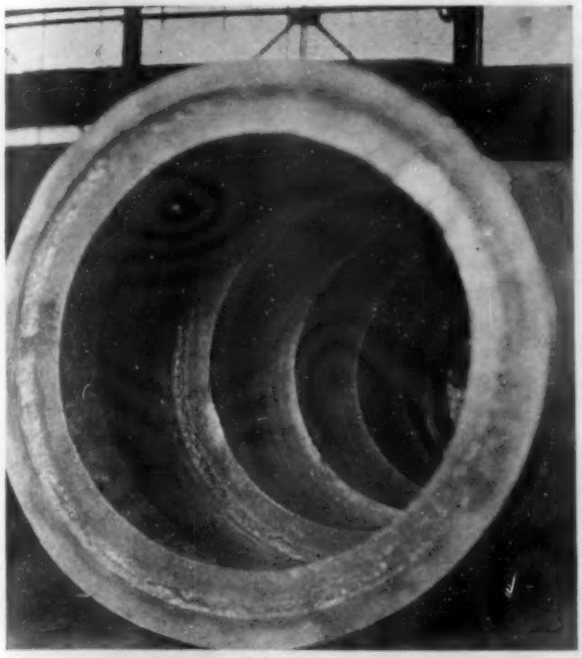


Fig. 26—Welded Bearing Rings in Stern Tube

welding and thus minimize shrinkage and warping. Next the distance pieces were welded to the pipe as shown by Fig. 23.

Temporary braces were then welded to these distance pieces and connected to turnbuckles which were secured to the bending slab to keep the stem from warping and twisting as welding progressed. These braces also held the pipe secure against the form. The side plates were then fitted and tack-welded to the distance pieces and to the pipe.

When all parts had been assembled and tacked, finish welding was started at the center and worked toward both ends. First the distance pieces were welded to the side plates by the wandering method. Then the side plates were welded to the pipe, again using the wandering method. This method produced excellent results and fairness of the job may be judged from Fig. 24.

The welded section of the stem was then fitted to the casting. The joint was broken; the two parts were sent to the building ways and assembled in their final place on the ship, where the welded section makes an excellent appearance.

The following comparison of Weights and Costs is of interest:

Weight of portion of stem in question if made of cast steel	5100 lb.
Weight of portion of stem as welded	1923 lb.
Saving in weight	3177 lb.
Percentage saving of welding over casting	62.3%

	For 1 Vessel Per Vessel	For 4 Vessels Per Vessel
Estimated cost of		
Casting @ 12¢ per pound	$ 612.00	$612.00
Pattern	810.00	202.50
Fabrication	150.00	150.00
	$1572.00	$964.50
Cost of welded stem	850.00	850.00
Saving over casting	46%	11%

Other Welding Jobs in the Shop.—Figures 25 and 26 show the welded steel bearing support rings, finishing approximately $1\frac{1}{2}$ in. in thickness and 3 to 4 in. in width, in struts and stern tubes in place of the former practice of casting the rings in one with the barrel. The rings were first lightly tacked in place. Then the casting was placed with the barrel vertical and the upper side of each ring was welded, which permitted the welder to work in the flat position. Heavily covered fluxed electrodes were used. In welding each ring, a 3-in. increment was deposited. The welder then moved 90° and deposited another 3-in. increment. This layer was completed by the wandering method of welding and lightly peened after the layer was hand cold. The second layer was then deposited in the same manner, which gave a finished $\frac{1}{2}$-in. fillet weld. The casting was then turned end for end and the other sides of the rings were welded in the flat position. Figure 27 shows a pressed panel water-tight door built up by arc welding.

Other Shop Welding of General Interest.—Other large welding jobs have been done in this shop lately, which are not directly connected with the *New Orleans*, one example of which is given as of general interest.

This job covered the construction of five all-welded submarine rescue chambers, recently completed. These chambers are built up of 30-lb. medium steel plate, with fillet welds at seams and 90° butt welds for shell butts. The chambers were tested hydrostatically to a 400-ft. head. These chambers, as their name implies, are to be used for the rescue of the crews of sunken submarines. The rescue party inside the chamber haul themselves down to the submarine, connecting to the submarine hatch, entering the submarine and rescuing the crew and bringing the men to the surface in the chamber. The finished chamber and details of welding are shown in Figs. 28 and 29.

VIII. Installation on Ship

As previously explained, it has been attempted, wherever welded construction occurs on the *New Orleans*, to perform the maximum amount of sub-assembly on the welding slab in the shop and on the assembly skids. This permits the welder to do most of his work in the flat position under favorable working conditions, instead of welding vertically or overhead, perhaps in an uncomfortable position on staging in the vessel. Moreover, the quality and quantity of his work can be more frequently and easily checked by his supervisor and the inspector.

These assembled units are placed in the ship and connected up to the adjoining members, usually by tee-joints with double fillet welds. Examples of this are seen in the welded water-tight and oiltight floors, built-up framing, decks and bulkheads, previously mentioned. Figure 30 shows the connection of a main transverse bulkhead to the inner bottom by a double continuous fillet welded tee-joint.

Fig. 27—Water-Tight Pressed Frame Door

Method of Welding Forward End.—The welding feature of this vessel, which is of the most interest, is the construction of the forward 96 feet of the ship, including frames, bulkheads, longitudinals and shell plating, entirely by welding, except for the longitudinal seams of the shell plating. Unfortunately, this work is just getting under way and will not be completed for several months, so that all that can be given at this time is an outline of the procedure that will be followed.

In making a study of this problem, there appeared to be two distinct methods of constructing a welded ship. By the first method, all component parts would be erected in place, firmly secured in their final positions and welded. This Yard is fortunate in having an accurate mold loft so that structural parts can be laid out and fabricated in the shop with reasonable assurance that they will fit accurately in place when assembled into the ship on the building ways. This is in accord with the best modern practice of shipbuilding, which tends toward a minimum of "hand fitting" or "lifting of plates" to suit the actual shape of the ship.

It therefore seemed desirable as the best practicable shipbuilding method to secure parts in their final position, weld, and then stretch the weld or counteract its shrinkage in some way. This tendency to shrink with the parts fixed in position leads, of course, to locked-up stresses of indeterminate magnitude. It was hoped that these locked-up stresses could be reduced to a negligible amount by peening the welds, but the uncertainty as to the amount of residual stress and the expense of peening led to more favorable consideration of the second method.

The second method was based on the principle of relieving all shrinkage stresses by free movement of the part which is welded. The structural members are held together by being loosely bolted or tack-welded with tacks incapable of resisting the shrinkage stresses. Each part as it is welded moves, as necessary to relieve shrinkage stresses.

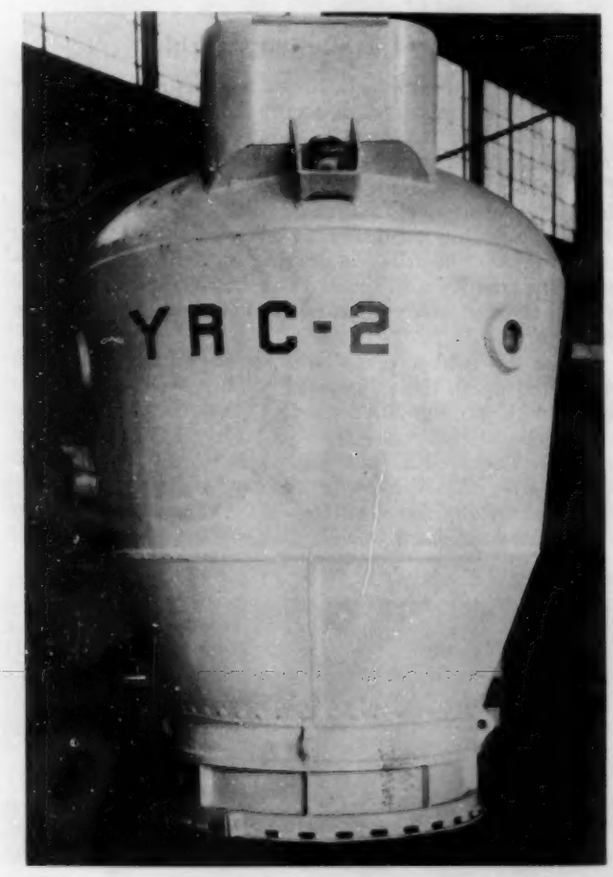


Fig. 28—Finished Rescue Chamber

Fig. 29—Details of Welding Rescue Chamber

It was believed that complete freedom of movement would result in probable loss of alignment and designed dimensions in the finished structure of the ship and would necessitate an excessive amount of "hand fitting" in finishing the structure. A method was therefore adopted which is believed to combine the best features of both schemes.

In general, this method consists of erecting an interior framework of frames, bulkheads, deck beams and longitudinals, assembled in the correct position and welded together to form a rigid framework in a sequence which results in a minimum of unrelieved shrinkage stresses. This rigid interior framework is covered by an envelope of shell plating and deck plating. Shell and decks are first welded into large units while free to move, so that shrinkage strains in these important members are fully relieved by free movement. This envelope is then secured to the interior framework in such a way as to cause the least amount of shrinkage and change in the dimensions of the ship.

Detailed Sequence of Operations for Forward End.—The proposed procedure for welding the forward end of the *New Orleans* is as follows:

1. Erect flat and vertical keel and rider plate, A and B strakes of shell, transverse frames, transverse bulkheads, longitudinals, deck beams, deck stringers and shell above B strake.

2. Secure all transverse and longitudinal members to each other by tack welds, to form a fair and rigid interior framework.

3. Secure all transverse and longitudinal members to the shell by means of bolts. The bolt heads shall be welded to the inside of the shell. Small angle clips shall be tack-welded to longitudinals and transverse bulkheads with oblong holes in the clips to permit free fore and aft movement as shell butts are welded. Transverse frames shall be secured to the shell by two bolts, one welded to the shell on either side of the frame with a small angle clip pulled against the frame by the two bolts.

4. "Finish weld" butts of all continuous longitudinal members, including deck stringers, starting at frame 22 and working forward.

5. "Finish weld" all longitudinal members to transverse members, starting at frame 22 and working forward. At frame 22 start at the keel and work upward to progress about equally on the port and starboard sides. On frame 21 start at the top and work outboard and downward. Then start at top and bottom on alternate frames and complete each one before proceeding to the next.

6. "Finish weld" shell butts starting on A strake, at frame 22, and working forward. In welding these strapped butt joints, one fillet weld shall be made first, then the butt weld, and finally the last fillet.

7. "Finish weld" all longitudinals to the shell, starting at the after end at frame 22 and working forward progressively on both sides.

8. "Finish weld" all transverse members to the shell, starting at frame 22 and progressing equally on port and starboard sides.

9. Put interior deck plates in place and weld them to the deck stringers, which have already been completed as longitudinal members. The wandering method shall be used to avoid excessive shrinkage.

10. Heavily covered fluxed electrodes shall be used for welding in the flat position. Bare electrodes shall be used for tacking and for welding in the vertical and overhead positions.

Fig. 30—Connection of Main Transverse Bulkhead to the Inner Bottom by a Double Fillet Welded Joint

Welding Seams and Butts of Plating for Tightness.—On the sides of the vessel behind the belt armor plates, it was desired to have the hull structure oiltight. The design, therefore, called for welding these seams and butts. Strength is provided by riveted joints and the welding is for tightness only. The structural plating in this locality is of high carbon alloy steel of special heat treatment, which is not readily weldable.

Some yards had difficulty with these welds because of cracking. At this Yard the plates were rigidly fixed before welding since no shrinkage or change of shape could be permitted in this part of the ship. The weld was deposited in two layers in a 60° vee with heavily covered fluxed electrodes. The first layer was lightly peened while hand cold. The second layer was chipped off flush and then roughed with a caulking tool for tightness. When these welds were made with a $^{3}/_{16}$-in. electrode and 285 amp., they cracked; when made with a $^{1}/_{32}$-in. electrode and 185 amp., no difficulty was experienced.

IX. Inspection and Testing of Welds

Inspection.—The New York Yard separates the function of inspection from that of production. The responsibility for high grade workmanship rests with the supervisors of the production organization. These supervisors, however, have many other responsibilities which, while not equally important, often seem more pressing at the moment. For this reason a welding inspector has been appointed, under the direction of the welding engineer, whose sole function is to inspect all welds in the ship for quality. It is the duty of the inspector to

1. Inspect each day the work of all welders on the vessel to determine compliance with plan and quality of workmanship. He marks with a yellow crayon, for the information of the piece work counter, all work that he rejects and makes a written report of such work to the welding engineer, with a copy to the foreman shipfitter.

2. Apply a gage to each weld to see that it meets the size required by plan.

3. Examine each weld carefully for undercutting, overlapping, overheating and improper fusion on the sides of the plates or the edges of the welds.

4. Check each welder during the progress of his work to see that proper values of current and voltage are being used, that proper fusion is obtained and that welds are finished off smooth with all craters filled.

5. Make periodic check tests of welders whenever he considers it desirable by supplying the welder with two pieces of medium steel plate 6 x 3 x $^{3}/_{8}$ in. thick. The welder, without changing his current and voltage values and size of electrode, fillet-welds these pieces together with a 2-in. overlap. The plates are then wedged apart in the presence of the welder and observations made as to fusion, penetration, porosity and grain fracture.

6. Make hammer tests on the important welds to develop cracks or improper fusion.

7. Check the welder on particularly important work by means of check tests and by the use of recording ammeters and voltmeters.

8. Exercise every means at his control to obtain the highest quality of welding on all work.

Testing.—In addition to the routine inspection described above, all welded work is subjected to the usual strength and tightness tests of structural compartments, pressure tests of piping systems and tanks and overload tests of hoisting and weight-handling appliances.

Pressure Tests of Piping Systems.—A large number of welds are found to leak because of porosity when pressure tests on piping systems are applied. It is believed that the high percentage of leaks is caused by the fact that piping systems are usually led through double bottoms or cramped spaces, such as under the boilers or directly beneath the decks. To weld the joints of these systems, the welder has to work under extremely unfavorable conditions and with a minimum of supervision. It is hoped that, as work progresses on this

vessel, the improvement in the quality of the average weld and the better functioning of the inspection will reduce the number of leaks which are found when pressure tests are applied.

X. General Principles Learned in the Construction of the U. S. S. *New Orleans*

Importance of Training Drafting Room to Welded Design.—If the cost of building an all-welded ship is to compare favorably with the cost of a similar riveted ship, the drafting room must be carefully trained to design welded structures which permit a maximum amount of sub-assembly in the shop and which then permit these sub-assemblies to be erected and regulated in the ship with the minimum effort.

Revised Specifications for Plates.—Navy Department Leaflet Specifications for steel plates require that "all plates shall be flat, free from seams, etc." and that galvanized plates shall be "commercially flat." In the past, it is believed that these requirements have been interpreted liberally so that plates which appeared to be generally flat were accepted. With all-riveted construction, this matter is not of any considerable importance. With all-welded construction, it is essential that the plates be initially flat if the finished structure is to be fair and true to dimensions.

Heat Distribution.—An outstanding lesson learned is the importance of avoiding too much local heat. Most of the difficulties caused by welding are due to shrinkage on cooling of the weld. In overcoming these difficulties, the Yard has found that, important as it is to establish a definite sequence of procedure for doing the work, it is of even greater importance, in securing a successful result, to distribute the heat by skipping about and stepping back so that no one locality is subjected to too concentrated a heating effect with its subsequent excessive contraction on cooling, which produces locked-up stresses in the structure and causes warping and distortion.

The amount of skipping about necessary depends primarily on the thickness of the plate being welded. In a very light plate it may be desirable to weld 3 in. and skip as much as 24 in., while on a plate $^3/_8$ in. thick, the ordinary stepback method of welding 6 in. and stepping back 12 in. to start the next 6 in. increment will probably prove satisfactory.

Shop Assembly.—In the design of an all-welded vessel, it is essential to economy to provide the maximum possible amount of sub-assembly in the shop. Frames, decks, bulkheads and fittings should all be designed with this in mind. It should be possible to take the individual pieces of these structures, dog them down on the welding slab and weld in the flat position under favorable working conditions rather than on the ship where it may be necessary to weld in an overhead position from a staging exposed to the weather. This secures better and cheaper welding and, in addition, if the job should warp or distort, it is much easier to straighten it in the shop than after assembly in the ship.

Necessity for Excellent Shipfitting.—It seems desirable in all-welded construction to secure a particularly accurate and careful job in mold loft and shop work. As previously mentioned, orthodox riveted construction affords a large number of holes for regulating the structure, for pulling it to the exact shape and position desired and for securing metal-to-metal contact.

In welded construction it is slow and expensive to pull up work which is a poor fit, particularly where much shape is involved. Furthermore if metal-to-metal contact is not secured, the designed throat area and strength of weld can only be obtained by increasing the size of the fillet by an amount equal to the space between the parts which fail to make contact. This requires the deposit of a much greater volume of metal and consequent increased cost.

Use of "Helper Welders."—A study of cost in welding operations has shown the desirability of training either mechanics who do assembly work or their helpers to be able to tack-weld. For instance, in the pipe shop, a large number of built-up fittings are being made for the various piping systems of the ship. As these parts are shaped and placed in position, they must be tack-welded. If a welder is assigned to each job, the welder loses much time standing around and the labor cost of the job is substantially increased. If no welder is assigned until the job is ready, the mechanic and helper will stand around and wait for the welder. This applies equally to a shipfitter assembling structural work in the shop or on the ship. The solution seems to be to have the mechanic or helper sufficiently instructed in the art of welding to be able to tack the part the instant it is ready.

Instruction in Welding for Shipfitter Supervisors.—The general supervision of and responsibility for the hull structure rest with the supervising shipfitters. These men were sent to the welding school for two hours' instruction each day for three months. They acquired in this time a good knowledge of the possibilities and limitations of welding and are thus able to control the general structural work far more intelligently.

XI. Conclusion

There can be little doubt that a material saving in weight can be effected in designing structures for the use of welding by eliminating faying flanges, reducing widths of overlaps, by proportioning the members such as stiffeners and beams to the loads they must bear, etc. The weight thus saved can be used for increased carrying capacity or "pay load" in a merchant vessel and for increased fighting qualities in a warship.

Definite figures are not available at this stage of the work as to comparative costs of riveted and welded construction at this Yard. From close observation of the work in progress, it appears that on flat work where only straight lines are involved, costs are less by welding but that much or all of this saving is lost in fitting and assembling the structure where much shape or curvature of the vessel is involved.

The rapid technical developments of recent months, which permit the making of welds in medium steel with tensile strength of the weld metal superior to that of the base metal and elongation equal to that of the base metal, have removed many of the design difficulties in the way of an all-welded war vessel.

When an alloy steel of high physical characteristics and suitable welding qualities is commercially available, welded construction can be applied to the ballistic parts of a vessel and to the important strength members.

Some definite and mechanical means of inspection of welds which would eliminate the human element and which is adapted to conditions on board a vessel under construction would do much to give designers that confidence in welding which is now felt by those intimately concerned with the practical production and inspection of welds.

When, in addition to the above problems, the practical difficulties connected with shrinkage can be solved, in a way which will not cause excessive "hand-fitting" and will not interfere with economical methods of ship construction, an all-welded war vessel would appear entirely practicable.

Cause and Cure of Intergranular Corrosion in Austenitic Steels

By JOHN A. MATHEWS

†This paper will be presented at the Annual Meeting of the American Welding Society to be held in New York, April 27th to 29th. Mr. John A. Mathews is Vice-President and Director of Research, Crucible Steel Company of America.

WITHIN the past 4 or 5 years there has come into prominence a new class of materials characterized by their resistance to corrosion. These are most readily fabricated into chemical apparatus and similar articles by welding methods. This paper, however, might properly be classified as dealing with "properties of materials." The writer would not presume to advise members of this Society on the art or technique of welding, but would like to discuss some of the effects of welding upon the properties of these materials and possible means of alleviating the deleterious effects produced by welding operations. Our entire discussion will be limited to these phases of the question. We shall not consider the effect of long time holding of these materials at operating temperatures within the embrittling range. That is another question which demands further consideration.

While these materials are rather new to industry they are not of such recent development as is generally supposed. They seem to have originated at the Krupp Works in Essen just prior to the Great War and during the war similar products were studied in this country, notably by C. M. Johnson of the Crucible Steel Company and by P. A. E. Armstrong, formerly of the Ludlum Steel Company. The work of these two men had to do primarily with forged and rolled products. There were also a number of workers in this country who developed somewhat similar materials from the foundry standpoint for castings. The American workers developed their products without knowledge of the prior work at Krupp and along somewhat different lines. It would appear that primary attention at the German works was devoted to corrosion resistance while in the earliest American work the idea of heat and scale resistance was first emphasized. Our own investigations began in 1917 and various products were displayed at the first Exposition of the American Society for Steel Treating 11 or 12 years ago. The exhibition included hot rolled and forged specimens as well as cold rolled and wire drawn to very fine sizes. The materials and their properties were described by Johnson at the same time. Nevertheless, it seems but a very few years ago, when, having interested a chemical manufacturer in one of our materials for containers for shipping a certain chemical, we were utterly unable to locate a fabricator who would either weld or deep draw the vessels wanted, from this new material—"Rezistal."

It is to be regretted that these highly alloyed products are called "steels," for in many of their characteristics they differ so widely from ordinary steels with which we have been familiar for generations that fabricators are apt to become confused and disconcerted in attempting to use them because of their lack of appreciation of the fundamental differences in their behavior. The ordinary commercial structural steels are known as "ferritic" because the iron is always in the alpha or magnetic modification. It is widely known that such steels may be annealed or softened by heating to temperatures around 1400/1500° F., usually followed by slow cooling. It is known that quick cooling from about the same temperatures will produce hardening and that serious over-heating results in a great coarsening of the grain and brittleness and in many cases, cracking. It is also widely recognized that these steels are very subject to rust and corrosion and estimates upon world losses due to corrosion have been made from time to time which run into fabulous figures. In contrast with ordinary steels the austenitic chromium-nickel alloys are essentially non-magnetic although some of them may be made very slightly magnetic by certain heat treatments. If we want to anneal them we take them up to some such temperature as 2000° F. and quench them in water. The annealing process as employed for ferritic steels will harden some of the austenitic steels to a slight extent. However, they may not be hardened at all in the ordinary sense in which we harden the ferritic steels. They are somewhat hardened by low finishing temperatures on hammers or rolls and may be very greatly hardened by cold work in rolling or drawing. Some of them become magnetic as a result of cold work. I recall seeing some deep stampings being made a few years ago, the operation requiring an intermediate softening. At the end of the first draw the parts to be softened were picked up with an electro-magnet and conveyed to the annealing department. After they had been softened they had to be carried to the second drawing process by the ordinary methods of conveyance!

The temperatures used for annealing ordinary steels are, in general, those which bring about the condition known as intergranular weakness and susceptibility to corrosion in austenitic steels. This feature will be discussed in more detail later. In contrast with ordinary steels, the austenitic alloys become more ductile the higher they are heated prior to quenching and coarse grain in them is an evidence of ductility. A coarse grain once induced cannot be removed by simple normalizing nor any other heat treatment but only by hot or cold work. In their softened condition when subjected to a tensile test they behave like bronze, in that they elongate throughout the entire gage length and the test piece acquires a roughened surface. No matter how much you may know about ordinary steel you must learn to think in entirely different terms when you work with the austenitic chromium-nickel alloys.

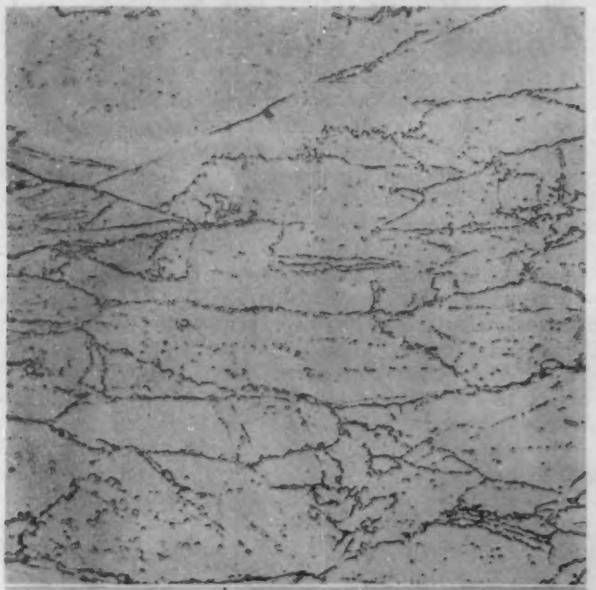
Intergranular Corrosion

Intergranular corrosion is by no means limited to the austenitic corrosion resistant steels. We have long been familiar with the phenomenon known as caustic embrittlement in soft steels. During the earlier investigation in this country of the synthesis of ammonia from atmospheric nitrogen, Mr. J. S. Vanick conducted experiments showing that many ferrous and non-ferrous alloys of the type ordinarily used for construction purposes are seriously subject to intergranular attack under the action of strongly reducing gases at high temperatures and pressures; in fact, the most resistant material with which he experimented was one of our Rezistal Steels, a nickel-

chromium-silicon alloy, which after six months of exposure showed a discoloration only 0.20 mm. deep in the 4.5 mm. wall of the tube being tested. Many of the materials with which he experimented showed complete penetration of 4.5 mm. in as short a time as two weeks. The austenitic steels, therefore, are not the only alloys subject to this defect but under some circumstances are by far the best materials available to resist it.

As has been intimated, when the austenitic chromium-nickel steels are reheated for any purpose between temperatures of 1000/1500° F. a change takes place in their structure which renders them subject to attack by many electrolytes, this attack taking place between the grains so that after long duration the material becomes very weak and brittle and in some cases may be even crumbled with the fingers. This is known as intergranular corrosion. Other less fortunate names have been used, such as weld decay, intercrystalline brittleness, etc. The usual explanation for intergranular corrosion is that at the embrittling temperatures between 1000/1500° F. carbides are thrown out of solid solution in the austenite and precipitate at the grain boundaries. Each atom of carbon combines with about 15 times its own weight of chromium to form the chromium carbide. On precipitation it is believed by many that there is an impoverishment in the chromium content immediately surrounding each carbide particle. This does not mean a general impoverishment or a serious lowering of the chromium content of the entire grain but a severe local impoverishment around the carbide particles themselves. It is further believed that because of the difference in potential in adjacent areas, due to varying of the chromium content, corrosion becomes possible. Under the microscope the widening and darkening of grain boundaries are noted and in specimens that have been subjected to certain electrolytes one can readily trace the penetration following the grain boundaries on which the carbides are precipitated. While no better hypothesis has been offered there are some features which lead us to think that there may be other elements that may be taken into consideration and that the explanation is not complete. In the steel commonly designated as 18–8, meaning 18% chromium and 8% nickel, re-heating within the embrittling range usually brings about a slightly magnetic condition and this is assumed to be due to the breaking-down of austenite and the production of alpha iron, but intergranular susceptibility also occurs in alloys much richer in chromium and nickel which do not become magnetic upon re-heating within the embrittling zone. It has been definitely shown that the higher the steel is heated, for softening, prior to being re-heated within the embrittling zone, the more readily it becomes susceptible to intergranular attack or, more specifically, the coarser the grain induced by the high temperature anneal the more susceptible the material to intergranular corrosion on re-heating, and if the original hypothesis is correct this means that the larger the grain the more readily the carbides appear at the grain boundaries on re-heating. It has been suggested that the reason the small grain steel, after re-heating, is less subject to attack than the coarse grain material is because the extent of grain boundaries is greatly increased the smaller the grain, and therefore such carbides as precipitate are spread out over a much longer total distance of grain boundaries. The appearance of microphotographs No. 3 and No. 4 might suggest that all the carbides have suddenly appeared at the grain boundaries. This, however, would presuppose the migration of carbon or carbide particles from the center of the grains to their peripheries. In spite of the fact that there is no evidence of carbides in the center of the grains yet we found, a good many years ago, upon analysis of some thoroughly embrittled steel which could be powdered with the fingers after treatment with the copper sulphate–sulphuric acid solution, that the analysis of this powder checked up completely with the heat analysis of the material used. Mr. F. R. Palmer of the Carpenter Steel Company later reported similar findings. This indicates that for some reason or other there is a localized precipitation of carbides but not a general precipitation throughout the grain and that there is probably no traveling of carbide to the grain boundaries but that the proportion of carbide which exists there in solid solution after the high heat treatment or anneal is precipitated, leaving the carbides in solid solution remote from the grain boundaries intact. The fact remains, however, that the large grain structure is more susceptible than the small grain structure for the same steel. We have found that a plain chromium steel containing 26%

Fig. 1—Normal Structure of KA-2 Alloy as Forged. Magnification 500 Diameters. Etched with Marble's Re-agent



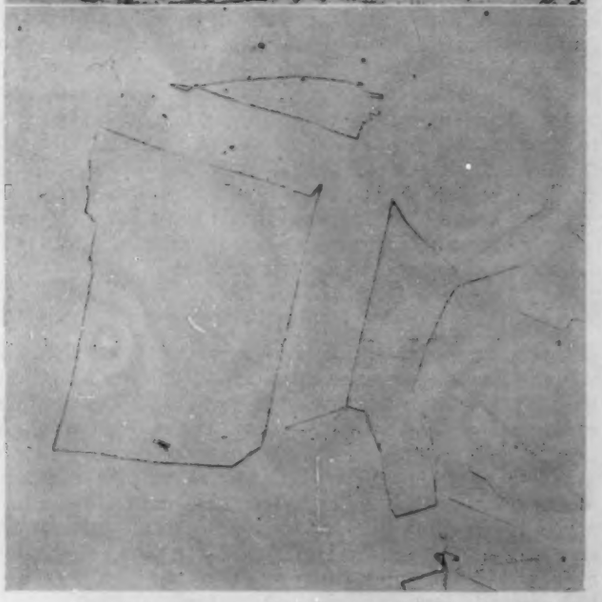


Fig. 2—KA-2 Steel Re-heated to 2100° F. and Water Quenched. Magnification and Etch Same as Fig. 1

chromium is subject to intergranular corrosion when quenched from 1800° F. followed by re-heating at 1000° F. In this steel such precipitation as occurs is also concentrated at boundaries, but the steel may also contain many original carbides that were never in solution. Furthermore, assuming that this steel contains 0.15% of carbon and that all of this carbon was precipitated, it would remove from solid solution 2.25% chromium, leaving slightly less than 24% of chromium in solid solution which would seem to be an adequate amount to resist attack. Nevertheless, our experiments show that the steel will fail from intergranular attack when boiled in a solution of 10% copper sulphate, plus 10% sulphuric acid which is the standard test medium for showing the presence or absence of intergranular susceptibility.

It is difficult to understand, in connection with the theory of intergranular corrosion which assumes localized areas of chromium impoverishment, why diffusion does not take place within a reasonable length of time bringing about a homogeneous distribution of chromium in austenite, thereby correcting the tendency to corrosive attack. Some 35 years ago my old friend and teacher, Sir William Roberts-Austen, demonstrated that solid gold will diffuse in solid lead at atmospheric temperatures and that the rate of diffusion is increased when the metals are heated to a temperature well below the melting point of lead, while the rate of diffusion is vastly accelerated when the lead is just molten and the gold is still far below its melting point. This work was done at temperatures much below those represented by the embrittling zone of 1000/1500° F. at which temperatures we might reasonably expect the rate of diffusion to be quite rapid in steel. Tests in which austenitic steels have been held within this range for very long periods of time do not seem to bring about a correction for the susceptibility produced. There is some evidence that at the higher temperatures within this range, say, from 1400/1500° F., some slight improvement does result with time which may be due to coalescence and growth of carbides into larger masses as well as to diffusion.

This brings me to suggest the idea that carbide size may be of very vital importance in the consideration of intergranular corrosion and it is possible that it is sizes below the limits of visibility under the high power microscope which produce maximum susceptibility. It has been noted that original carbides contained in these steels as hot rolled, which are relatively of large size, seem to be without influence in the matter of intergranular corrosion but when all initial carbides have been taken into solution by a high temperature anneal and reprecipitated by reheating between 1000/1500° F., then we have a condition of ready susceptibility to intergranular attack. The limit of visibility under the microscope is about one-tenth of a micron. Dimensions of the order of one-hundredth of a micron may be considered colloidal, and from one-hundredth to one-thousandth of a micron may be considered as molecular. The number of carbide particles corresponding with these dimensions for a given amount of carbon in the steel represent a tremendous increase both in number and also in exposed surface. This phase of the question does not seem to have received much attention.

The connection between this and the welding industry arises from the fact that in making either a gas or electric weld the material adjacent to the deposited weld metal is inevitably subjected to a temperature gradient varying from that of the molten metal as deposited to room temperature. This will obviously include the total range between 1000/1500° F. in which range trouble is likely to occur. Whether it does occur or not depends to some extent upon the time at which the steel adjacent to the weld remains within this range of temperatures. We have found some steel subject to intergranular attack after as little as two minutes holding within this range. Since this temperature gradient is inevitable the next question that arises is what can we do about it?

Fig. 3—Prior Treatment Same as Fig. 2 But Re-heated for 100 Hours at 1200° F. Note Broadening of Grain Boundaries and Indication of Precipitation along Twinning Planes

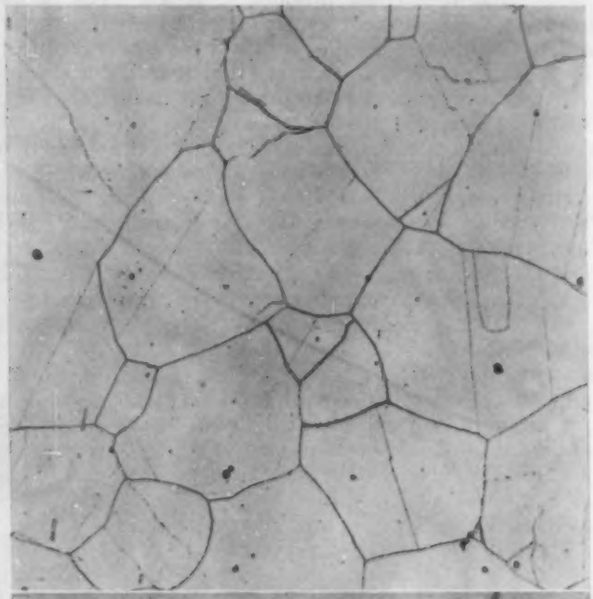
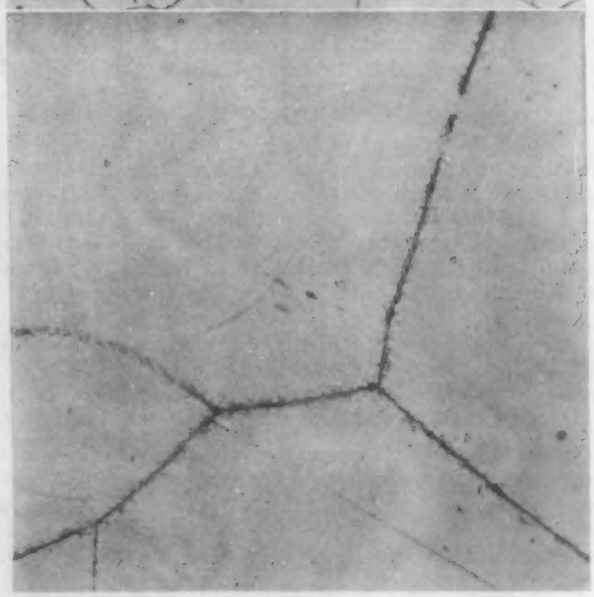


Fig. 4—Same as Fig. 3 but at 2000 Diameters Magnification



The Cure for Intergranular Susceptibility

The first method that has been found satisfactory in most cases results from the manufacture of an alloy with the lowest possible carbon content. The solid solubility of carbon or carbides in this steel is extremely low, possibly not over 0.03 to 0.04%. However, with carbon below 0.07% it is usually found that danger of intergranular attack is minimized probably because there is so little carbon to be precipitated upon re-heating that no attack occurs or that occurrence would be so extremely slow as to be virtually negligible. It should also be

recalled that while some electrolytes might bring about the attack others would be very much weaker in their attack and might not produce it at all. The copper sulphate–sulphuric acid solution is extremely drastic and if material after re-heating stands it for a period of from 100/500 hours, it is quite likely that it would withstand most of the commercial electrolytes with which the metal might come in contact for an indefinite period. We do not as yet have a quantitative measure of the strength of attack of the wide series of electrolytes against which the various austenitic steels possess ample general resistance to corrosion to warrant their industrial use. Such information is highly desirable but it would take a very long time to acquire even reasonably complete data.

The tendency of various electrolytes to produce intergranular corrosion undoubtedly varies between extremely wide limits, possibly not of the same order as particle sizes just referred to, but nevertheless the action of many industrial electrolytes with which these materials come in contact must be extremely slight or totally negligible; otherwise we should have had a great many more reports of failures of welded structures than we have had. The possibility of such failures, however, must always be taken into consideration and guarded against.

The second method of prevention that has had considerable application and that is very certain in its effect, results from heat treating all over the welded part. After a weld has been made and presumably carbide precipitation has occurred in the regions adjacent, it is possible to totally remove this effect by re-heating to some temperature—usually from 1800° F. or upward, depending upon the amount of total carbon or carbide which must be taken into solution. This high heat treatment also removes stress effects introduced during the process of fabrication and brings about once more a uniform or homogeneous condition throughout the entire part being manufactured. Such treatment is readily performed with small objects but not so readily performed in the case of large tanks or vessels and may be totally impossible in the case of still larger structures that must be erected on the spot where they are to be used; i.e., structures so large that they cannot be produced in the fabricator's shop and transported. Some fabricators have provided themselves with heat treating furnaces of tremendous size in which they can handle vessels as large as can be shipped by rail, but handling such a piece of work without distortion at temperatures from 1800° F. and upward is a serious matter, particularly since to produce the best results the cooling must be at a rapid rate, such as air cooling in the case of very light gages, or water quenching in the case of heavier gages; in fact, if the rate of cooling is not sufficiently great it is doubtful whether the re-heating in itself is beneficial or detrimental other than for whatever effect it has in the removing of mechanical stresses. Large size bars, for example, when cooled in air from a temperature of 2000° F. will usually be found subject to intergranular attack simply because the rate of cooling has not been fast enough to retain the carbides perfectly in solid solution. When heat treatment all over is possible, carbons from 0.07 to 0.15 are in many cases preferred.

Fig. 5—Shows Intergranular Corrosion Following Grain Boundaries, the Dark Areas Indicate Where Grains Have Fallen Out. 100 Diameters, Unetched. Taken from Welded Expansion Joint Which Failed in Service

In connection with large structures produced in Great Britain a sort of compromise method of construction has been suggested which consists of welding the largest sections that can be heat treated and assembling such sections by riveting. Possibly I should not venture to suggest riveted construction before the AMERICAN WELDING SOCIETY! Furthermore, it is not impossible but that the temperature induced by contact with a hot rivet may result in the same kind of temperature gradient and carbide precipitation which results from welding. It should be recognized, therefore, that there are cases in which heat treatment all over is impossible and then arises the most serious question as to methods of prevention.

This brings us to the third method of prevention of intergranular susceptibility by the addition of certain other elements to the austenitic chromium-nickel steels which have been found to act as inhibitors to prevent, or very greatly retard, intergranular susceptibility. The exact way in which these elements function has not been explained in all cases but they have been tested sufficiently in the laboratory and elsewhere to prove that they may be extremely effective.

The idea has been advanced that all that is necessary is to produce a steel containing not over 72½% iron; in other words, to increase the chromium and nickel content slightly above the customary 18–8 ratio. The validity of this idea has not been proved; in fact, the hundreds of tests that we have made on the greatest possible variety of combinations of chromium and nickel have never shown one combination that cannot be embrittled by re-heating after high annealing and by the action of the copper sulphate–sulphuric acid solution. This we have found true with alloys containing not over 55% iron, as, for example, 25% chromium and 18% nickel; also with 25% chromium and 10% nickel. Alloys in which the nickel is higher than the chromium are more susceptible than those in which chromium predominates. We agree that some of the higher chromium-nickel ratios are somewhat more resistant than the customary 18–8 but we have never found any that possess total immunity—far from it. Extensive investigations carried on at the Krupp Works have shown that additions of titanium in properly balanced amounts bring about a remarkably resistant condition but the exact explanation of its efficacy I do not believe has been found. In a very extensive series of investigations covering 2 or 3 years time it was developed by Mr. Payson in one of our Research Laboratories that several elements, including not only titanium, but also silicon, vanadium, molybdenum and tungsten, are effective under certain balanced conditions of composition. The

exact limits or ranges of composition have not as yet been fully determined but the importance of his work is believed to be very great.

It was mentioned above that when ordinary 18–8 alloys are subjected to the embrittling treatment they may become slightly magnetic due to a breaking-down of austenite yielding some alpha iron; in fact, we have seen specifications which state that welded structures must be non-magnetic. The presence of magnetism is assumed to indicate a condition of susceptibility. In Mr. Payson's work, however, he deliberately set about to produce a composition which is magnetic, not only after the high temperature anneal, but also after the embrittling treatment or after welding. In this case the magnetism is due to the presence of delta ferrite which from the evidence of X-ray examination is supposed to be identical in atomic arrangement with alpha ferrite. It was discovered in our investigations that when an analysis was so adjusted as to produce a steel showing some magnetic susceptibility in the annealed condition we found very marked resistance to intergranular attack. Therefore, the presence or absence of magnetism in the finished structure is not conclusive evidence of freedom from intergranular corrosion. Austenitic alloys as high as 0.20 carbon were found to possess very great resistance to intergranular attack and this would seem to mean that in the future we may not be limited to the very difficult requirement of producing carbons below 0.07 from commercially available raw materials and in commercial furnaces and quantities. This requirement of excessively low carbon has imposed a very severe burden upon the producers of the austenitic steels and it is hoped that our recent work will ease this burden. These investigations were fully described by Mr. Payson in Technical Publication No. 464 of the American Institute of Mining and Metallurgical Engineers at their annual meeting in February last. It is too soon to predict the commercial importance of this work and other work remains to be done in determining exact limits of composition which are most suitable for the individual requirements of the chemical industry.

It is not necessary to review Mr. Payson's work in great detail at this time but merely indicate the scope of his investigations. These included the examination of many variables. First, the effect of various temperatures within the range that has been so frequently referred to, namely, tests at 100-degree intervals from 900° to 1600° F. These show, in general, that 1200° F. is the most harmful single temperature and that at or below 1000° F., or above 1500° F., serious injury is not apt to result from re-heating. Second, having established the most critical temperature range the effect of variable time at heat received attention. Various periods such as 2 minutes, 10 minutes, one hour and longer periods up to 700 hours were studied. This survey indicated that 10 minutes at heat might be considered as a sufficient length of time for the majority of our tests because presumably in welding, parts adjacent to the weld are not subjected to temperatures within the embrittling range for longer than 10 minutes. Third, having studied the effect of time and temperature an extensive series of standard and modified analyses were tested, both in welded and unwelded samples. Before the copper sulphate–sulphuric acid solution was adopted as standard several other electrolytes were tested. Fourth, in steels highly resistant, but not perfectly resistant, to intergranular corrosion, it was found that in some cases susceptibility resulted at one temperature only within our range of tests. In other cases two or three temperatures might produce susceptibility and in other cases it was noted at all temperatures tested. A steel subject to one or two temperatures only would presumably be quite satisfactory in nearly all commercial applications. Fifth, in the case of our most resistant products, tests in boiling copper sulphate–sulphuric acid solution were in some cases continued up to one and one-half months without producing the least sign of embrittlement.

Even with these steels there can be no objection to applying the method of re-heating after welding of the finished structure for the relief of stresses. In regard to stresses and their effect upon corrosion a few words may be in order based upon our experience and observation. We have seen on several occasions tubes of 18–8 steel bent in hairpin form which have failed very rapidly in use at the bend itself while the straight and unstressed portions of the tube showed no attack whatever. Had such tubes been re-heated after forming they would probably have given a good account of themselves in service. On the other hand, tests that have been made of cold drawn and cold rolled 18–8 steel seem to indicate that it is very resistant to corrosion in the hard state. This indicates that uniformly distributed stresses, such as those produced in cold rolling or cold drawing are not as harmful as unequal stresses which may be produced in bending and forming operations. In other words, it would seem that there may be something in the idea of a stress gradient similar to the chromium concentration gradient which is to be avoided and therefore the relief of stresses whenever possible is to be recommended, but the absolute necessity of doing so will depend in a large measure upon the corrosive conditions to which the finished part will be subjected.

There can be little doubt but that the wider use of austenitic steels has been retarded due to fear of failure from intergranular corrosion. A very long step forward has been taken in methods to prevent the possibility of such failure. There are three methods which have been described which may be employed separately or altogether. The conditions leading up to intergranular susceptibility have been the subject of very thorough investigations on the part of many workers in many laboratories. The question of prevention has also had serious attention and it now seems that the reasons which have deterred many prospective users from availing themselves of the general corrosion-resistant advantages of these steels have been entirely removed so far as the great majority of potential applications in industry are concerned.

A Study of the Transformation Points of Fusion Weld Metal

By F. R. HENSEL *and* E. I. LARSEN

✦Paper to be presented at the Annual Meeting of the American Welding Society, April 27th to 29th, New York, by Messrs. F. R. Hensel and E. I. Larsen of the Research Laboratories, Westinghouse Electric & Manufacturing Co.

Introduction

THE AUTHORS have shown in their paper before the A. S. S. T., 1931, entitled "Age-Hardening Phenomena of Typical Fusion Weld Metal," that weld metal, although having the composition of nearly pure iron, exhibits entirely different metallurgical characteristics. They investigated particularly the changes in hardness, magnetic properties, electrical conductivity and tensile properties as well as the structural changes connected with aging and compared arc and gas weld-metal with low-carbon steels and ingot iron. This paper is a continuation of the previous work and is confined to the study of the transformation points of fusion welds.

Test Materials

The composition, gas and residue analyses of the investigated materials are given in Tables 1 to 3.

For the determination of nitrogen contents higher than 0.02% the following method was devised by E. W. Beiter, Analyst, Westinghouse Research Laboratories:

"Construct a still consisting of a 2–3 liter distilling flask, a trap to catch any spray which might pass over, a separatory funnel with glass stop cock, a condenser set in a vertical position and having a delivery tube suitable for immersing in 50 cc. of liquid contained in a 300-cc. Erlenmeyer flask.

"Put into the distilling flask 200 cc. of distilled water and add 35 cc. of sodium hydroxide solution (300 gm. to 500 cc. water). Also add a few pieces of zinc shot or mossy zinc to prevent bumping. Distill over about 25 cc. of water in order to free the apparatus of traces of ammonia.

"When the ammonia has all been driven out, place under the delivery tube a 300-cc. Erlenmeyer flask containing 25 cc. $N/20$ sulfuric acid and 25 cc. water. Add the steel sample, 5 gm. of which has been dissolved in 40 cc. 1:1 hydrochloric acid, to the distilling flask through the separatory funnel at such a rate that the liquid in the flask continues to boil rapidly. This breaks up the mass of ferrous hydroxide which would otherwise form and facilitates the liberation of the ammonia. Continue the distillation until approximately 150 cc. have come over and then titrate the excess sulphuric acid with $N/20$ sodium hydroxide using methyl orange as indicator. Starting with a 5-mg. sample 1 cc. of $N/20$ sodium hydroxide is equivalent to 0.014% N.

"In order to test the method a synthetic sample was made from ammonium chloride and 5 gr. of plain steel, the nitrogen content of which was determined to be 0.0035% (0.000175 gm. in 5 gm.). An amount of ammonium chloride was added which was equivalent

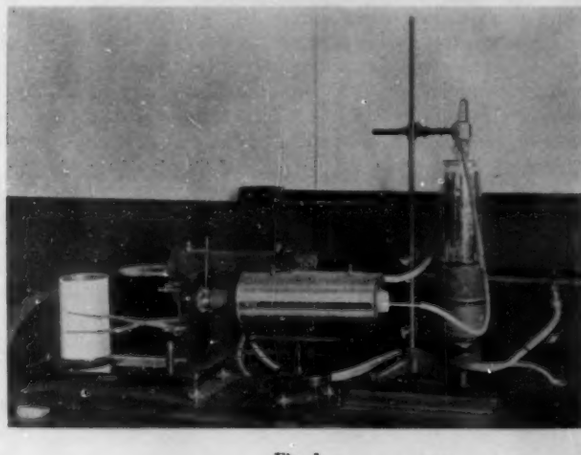
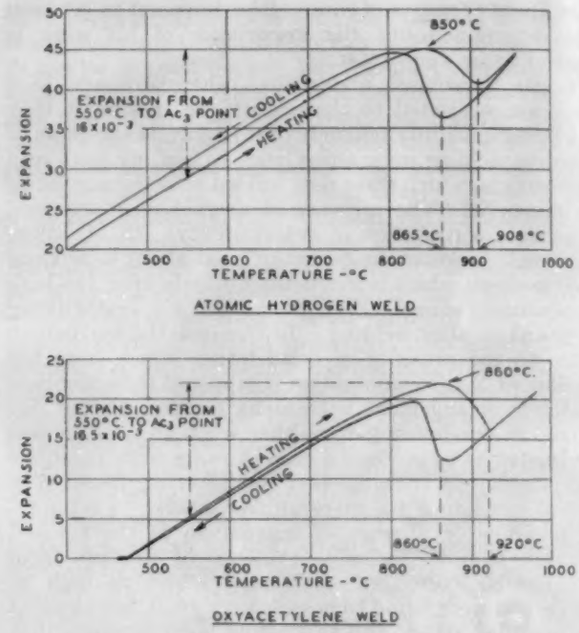


Fig. 1



DILATATION CURVES OF ATOMIC HYDROGEN AND OXYACETYLENE WELD

Fig. 2

Table 1—Chemical Analysis

	% C	% Mn	% Si	% S	% P
Coated Wire "W"	0.070	0.42	0.19	0.018	0.012
Coated Wire "F"	0.10	0.40	0.12	0.024	0.020
Bare Wire	0.027	0.006	0.004	0.03	0.016
Oxyacetylene	0.033	0.14	0.003	0.021	0.027
Atomic Hydrogen Weld	0.033	0.15	0.008	0.008	0.005*
Ingot Iron	0.02	0.04	0.008	0.043	0.009
Ingot Iron H_2 Annealed at 1400° C.	Trace	0.033	0.005	0.012	0.003

* The analysis of the atomic hydrogen weld metal compares closely with that of hydrogen fused pure iron. Especially noticeable are the low P and S contents. These constituents are apparently removed as H_2S and H_3P gases in the atomic hydrogen welding process as well as in the hydrogen melting process.

Table 2—Gas Analysis

	Vacuum Fusion Method			Beiter's Method
	O_2 Wt. %	H_2 Wt. %	N_2 Wt. %	N_2 Wt. %
Coated Wire "W"	0.133	0.003	0.056	0.060*
	0.094	0.001	0.029	....
	0.064	0.001	0.041	....
Coated Wire F-1	...	...	...	0.075
Coated Wire F-2	...	...	...	0.038
Bare Wire	0.259	...	0.127	0.147**
	0.183	...	0.093	0.128
Oxyacetylene	0.054	...	0.013	0.024
Atomic Hydrogen	0.053	0.005 (high)	0.017	0.037
Ingot Iron	0.08	...	0.004	0.0065

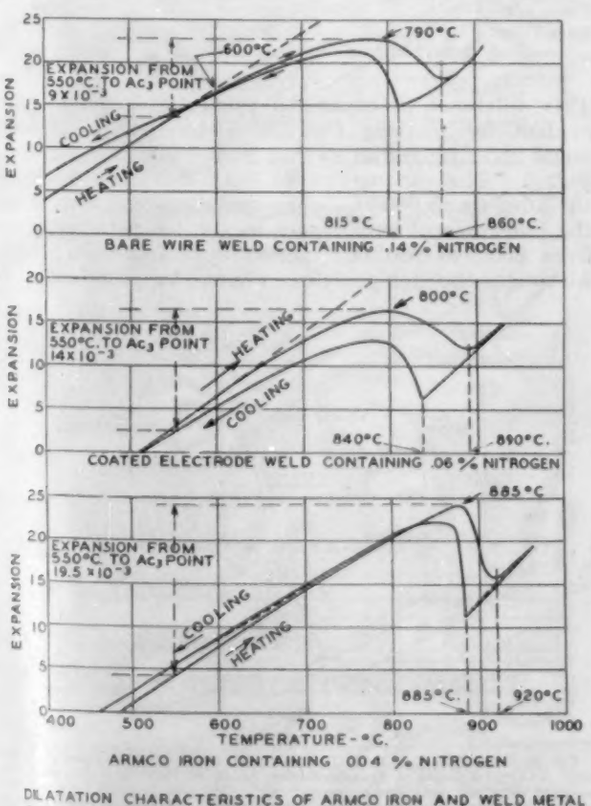
* This value is obtained if pads are built up in the air. If the weld metal is deposited, e.g., in a two-inch groove with the same coating the nitrogen content is reduced to 0.027% due to the self-shielding effect.

** The nitrogen content of a bare-wire weld is a function of the arc voltage or in other words, the arc length. This is evident from the following data for a certain grade of wire:

Arc Voltage	Nitrogen Content
13 volts	0.114
18 volts	0.121
24 volts	0.126
31 volts	0.135

Table 3—Residue Analysis

	SiO	Al_2O_3	MnO	MnS ($MnSiO_3$)	Total
Coated Wire "W"	0.128	0.010	0.018	0.091	0.247
Coated Wire "F"	0.096	0.011	0.015	0.084	0.206
Bare Wire	Less than 0.001	0.003	0.073	0.009	0.086
Atomic Hydrogen	0.002	0.016	0.007	0.026	0.051
Oxyacetylene	0.008	0.002	0.035	0.013	0.058
Ingot Iron	Less than 0.001	0.003	0.012	0.014	0.030



DILATATION CHARACTERISTICS OF ARMCO IRON AND WELD METAL SHOWING THE INFLUENCE OF NITROGEN ON THE A_3 POINT

Fig. 3

to 0.0070 gm. of N. On two determinations the amount recovered was 0.00719 gm. and 0.00722 gm. which, after subtracting the amount in the steel, leaves 0.00702 and 0.00704 gm. N."

The residue analysis was made according to a method described by G. R. Fitterer.[1] Since at the present time we have no method of determining the FeO content of the residue of iron and low-carbon steel the total amount of oxygen cannot be accurately stated.[2] In steels the

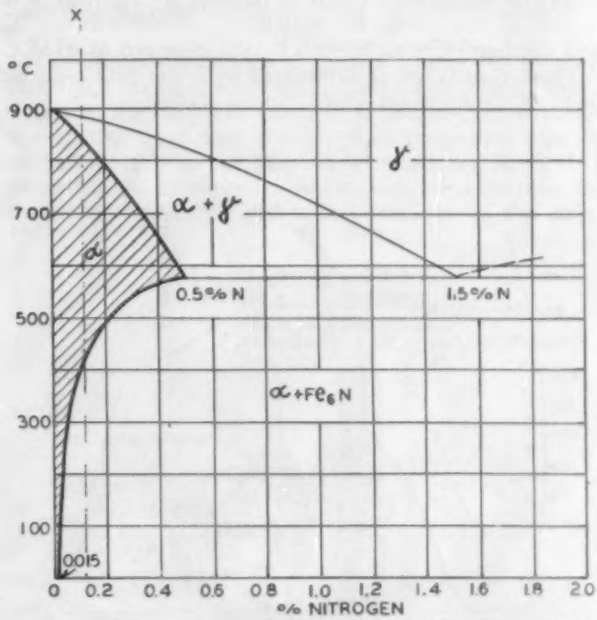


Fig. 4—Iron-Nitrogen Diagram According to Fry & Epstein. The Line X Indicates the Nitrogen Content of a Bare Wire Weld

total amount of residue is generally regarded as an indication of its relative cleanliness. It is quite interesting to note that the total residue of welds made with a coated wire is about three times as high as that of a bare-wire weld. Especially the SiO_2 and MnS, or more likely the $MnSiO_3$, contents of the coated wires are comparatively high. This is in agreement with the chemical analysis and is probably the result of the coating. The total amount of residue, however, is still within very reasonable limits.

Testing Apparatus

For preliminary tests the Chevenard dilatometer was found sufficiently accurate. In Fig. 1 a set-up for running tests under a gaseous atmosphere is shown. In the Chevenard Industrial Thermal Analyzer the expansion of the specimen (dilatation-time curve) and that of the pyros rod (temperature-time curve) are registered simultaneously on the drum of its chronograph. From these two curves a temperature-dilatation curve can be plotted if it is desired.[3]

In later work a dilatometer was used which was previously described by H. Scott.[4] The samples for the expansion tests had the following dimensions: length 4.02 ± 0.005 in.; 1/4 in. diameter, ends 1/8 in. radius.

[1] G. R. Fitterer, *Cooperative Bulletin* **51**, Carnegie Institute of Technology.

[2] For the FeO determination the Ledebur and Vacuum fusion methods are used most frequently.

[3] For a detailed description of the apparatus see: P. Chevenard, "Analyse dilatometrique des materiaux Durrod," Paris, 1929.

[4] H. Scott, "Expansion Characteristics of Low-Expansion Nickel Steel," *Trans. A. S. S. T.*, **13**, 829 (1928); "Expansion Properties of Low-Expansion Fe-Ni-Co Alloys," *A. I. M. E. Inst.* (Metals Div.), p. 507 (1930).

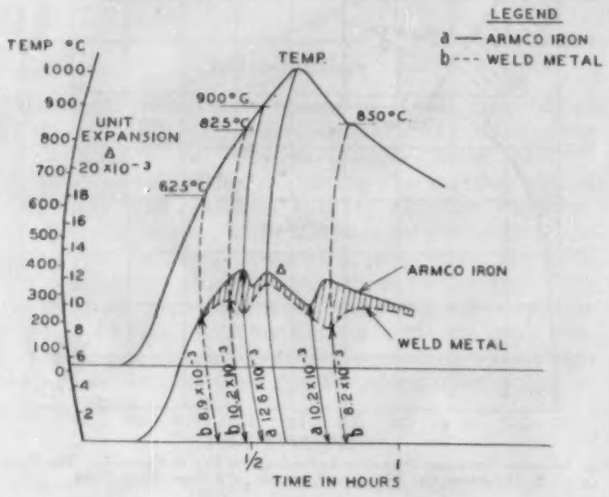
Test Results

The expansion-temperature curves of atomic hydrogen, oxyacetylene, bare-wire and coated-wire welds are compared with Armco iron in Figs. 2 and 3.

The following points should be noted:

1. The transformation points are lowered with increasing nitrogen content. Armco iron with 0.004% nitrogen shows, for instance, the beginning of the Ar_3 transformation of 885° C., atomic hydrogen and oxyacetylene welds with 0.020 to 0.030% nitrogen at 860° to 865° C., the coated rod with 0.06% nitrogen at 840° C. and the bare-wire weld with 0.14% nitrogen at 815° C.

These results are in agreement with the data reported by C. B. Sawyer[5] for iron-nitrogen alloys.



EXPANSION CHARACTERISTICS OF FUSION WELD METAL AS COMPARED WITH ARMCO IRON.
CHEVENARD THERMAL ANALYZER

Fig. 5

The effect of oxygen on the transformation points was studied by Tritton and Hanson.[6] However, no effect on the transformation points was found. The curves were run in vacuo in the usual heat gradient furnace using a Rosenbain plotting chronograph.

2. The temperature range of the alpha-gamma transformation increases with increasing nitrogen content.

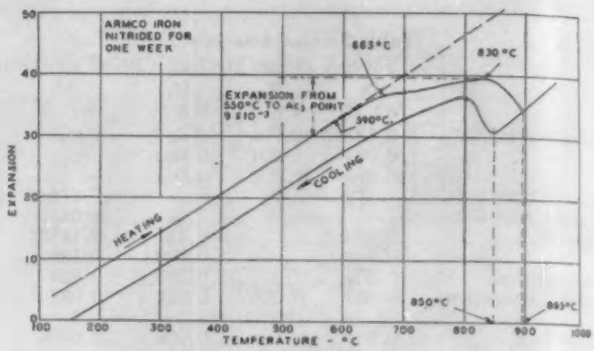
3. In the bare-wire weld there occurs at about 600° C. a noticeable deviation from the previous parabolic shape of the expansion curve. In the Chevenard curves this deviation appears as a definite kink. This deviation must be caused by the nitride eutectoid, Braunite. The eutectoid temperature is approximately 600° C. Although in the present iron-nitrogen diagram (see Fig. 4) the limit of solid solubility at eutectoid temperature is given as 0.5% nitrogen previous investigators found

[5] *Trans. A. I. M. E.*, p. 798 (1923). Sawyer found for iron-nitrogen alloys the following Ar_3 points:

% N_2	Ar_3
0.0306	843° C.
0.108	822° C.
0.269	780° C.

[6] F. S. Tritton and D. Hanson, *Journal Iron & Steel Inst.*, **110**, 90 (1924). They found the following temperatures as Ar_3 points for iron-oxygen alloys:

% O_2	Ar_3
0.12	885° C.
0.15	885° C.
0.21	880° C.



DILATATION CURVE OF NITRIDED ARMCO IRON

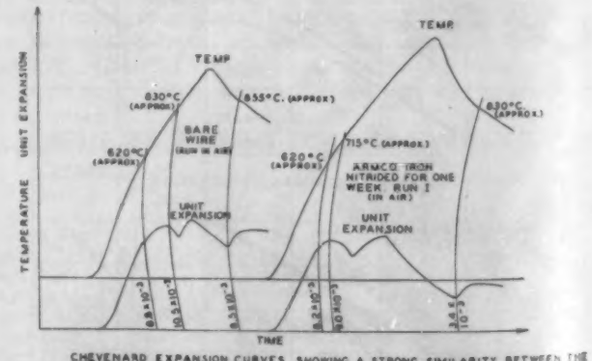
Fig. 6

Braunite at considerably lower nitrogen contents.[7] This might be explained by lack of diffusion or incorrectness of the present diagram.

4. On account of the transformational characteristics the expansion properties of the various types of welds are changed considerably in the temperature range from 600–900° C. This change also appears to be a function of the nitrogen content as seen from the figures below. However, it cannot be concisely explained by the present iron-nitrogen diagram inasmuch as we are dealing with a ternary or still more complex system.

Material	Expansion from 550° C. Up to the Ac_3 Point (4 in. Test Piece) 10^{-3} In.	% Nitrogen
Armco Iron	19.5	0.004
Atomic Hydrogen Oxyacetylene Welds	16–16.5	0.02 to 0.03
Coated Wire	14	0.06
Bare Wire	9	0.14

This difference in expansion properties is made quite evident by plotting the Chevenard curves of weld metal and Armco iron so that they overlap as seen from Fig. 5. The expansivity of both materials is nearly the same up to 600° C. The cross-sectional area shows the difference of expansivity in the temperature range from 600° to 900° C. caused by solubility changes. Although the temperature where the differences of



CHEVENARD EXPANSION CURVES SHOWING A STRONG SIMILARITY BETWEEN THE TRANSFORMATION POINTS OF FUSION WELDS AND NITRIDED ARMCO IRON

Fig. 7

[7] P. Epstein, *Trans. A. S. S. T.*, **16**, 19–65 (Oct., 1929). Epstein found with 0.142% nitrogen a transformation point at 605° C. However, his samples were not very homogeneous. C. B. Sawyer (loc. cit.) found with 0.108% nitrogen a transformation point at 610° C. With increasing nitrogen content the magnitude of heat absorption at that temperature grew which points to the eutectoid nature of this transformation.

Fig. 8—Chevenard Test Specimen of a Bare Wire Weld Before (Left) and After Nitriding (Right)

expansion occurs is fairly high, there is a possibility that it may have a bearing on practical consequences.

In order to strengthen the fact that nitrogen causes the changes in the transformational characteristics of welds, Armco iron samples were nitrided for one week in a stream of ammonia and tested afterward. The expansion-temperature curves in Fig. 6 as well as the Chevenard expansion-time curves in Fig. 7 show a striking resemblance between a bare-wire weld and a nitrided specimen. Slight deviations are explained by the facts that a nitrided sample is very inhomogeneous and that diffusion of nitrogen occurs during the test run. This explains especially the great amount of shrinkage during cooling as seen from Fig. 7. In nitriding weld samples the strange fact was revealed that they grow considerably more during the nitriding process than did Armco iron for instance. The growth of a Chevenard bare-wire sample after nitriding is clearly seen from Fig. 8.

The effect of a severe hydrogen anneal (12 hours at 1400° C.) on bare wire, coated wire and Armco iron is shown in Fig. 9. The effect of hydrogen anneal on the nitrogen content and the physical properties was described already in our previously mentioned A. S. S. T. paper.[8] The nitrogen as well as oxygen is more or less completely removed and the differences in the transformational characteristics between bare wire, coated electrode and Armco iron have disappeared. The Ac_3 points were found in all three cases at approximately 905° C. (See Fig. 9.) The tests were run in air. In testing hydrogen-annealed Armco iron and various other kinds of high purity iron (vacuum fused, hydrogen melted) under hydrogen atmosphere it was found[9] that the Ac_3 point was raised to 930° C. and that the temperature range of the transformation became very short. In establishing the solid solubility curve for FeO in Fe Ziegler[10] found that at approximately 900° C. the solubility increases very rapidly which probably explains that in air the transformation points of hydrogenized Armco iron and weld samples are not found

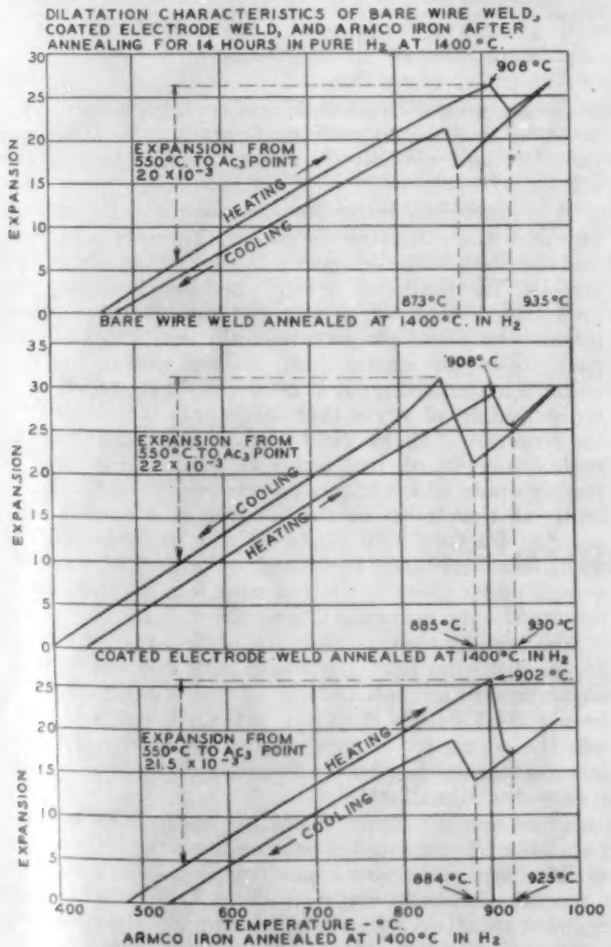
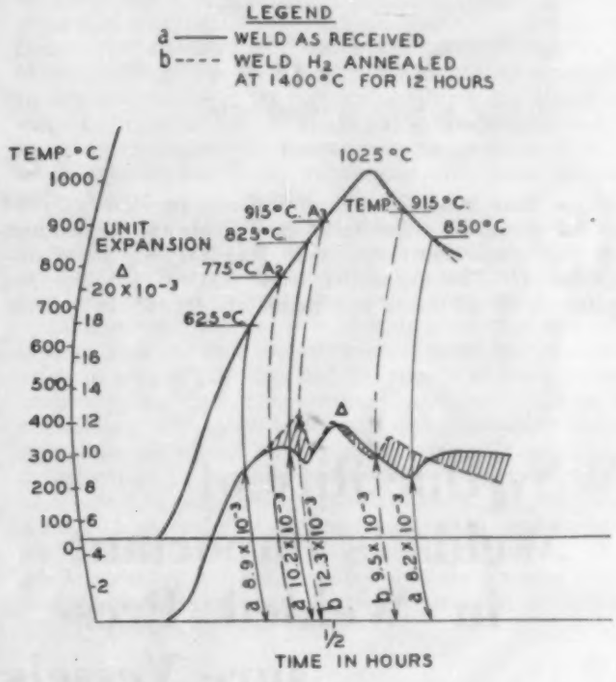


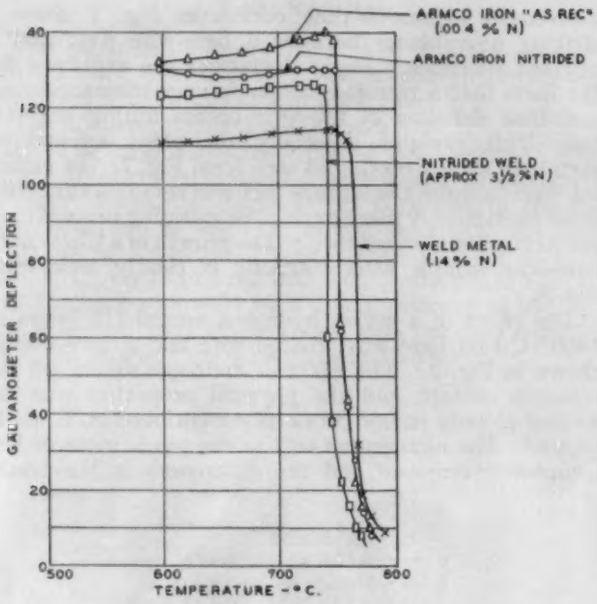
Fig. 9



DILATATION CHARACTERISTICS OF A FUSION WELD "AS RECEIVED" AND AFTER A HYDROGEN ANNEAL. (CHEVENARD THERMAL ANALYZER)

Fig. 10

[8] Given at Boston, Sept., 1931.
[9] F. R. Hensel, E. I. Larsen, Westinghouse Research Memo. 60-7421-3.
[10] N. A. Ziegler, Preprint A. S. S. T. Meeting, Boston, 1931.



EFFECT OF NITROGEN ON THE MAGNETIC TRANSFORMATION (A_2 POINT)

Fig. 11

higher than 905° C. The differences previously found in the expansion characteristics of welds and Armco iron in the temperature range of 600–900° C. have disappeared. The expansion from 550° C. to the Ac_3 point is in all cases approximately 21 × 10^{-3} inch.

In Fig. 10 the changes in the dilatation of a bare wire weld before and after hydrogen anneal are made apparent by plotting the Chevenard expansion-time curves on the same coordinates so that one is superimposed upon the other and the cross-sectional areas thus give the differences in expansivity.

Magnetic Transformation

According to our results nitrogen has no appreciable effect on the location of the A_2 point. From Fig. 11 it can be seen that the temperature of steep drop in galvanometer deflection or, in other words, of the drop in permeability[11] varies only 20° C. (750–770° C.) with a variation of nitrogen content from 0.004 to 3.5%.

Summary

1. Increasing the nitrogen content in the weld metal causes:
   (*a*) Lowering of the A_3 transformation point
   (*b*) Increase in temperature range of alpha-gamma transformation
   (*c*) Changes in expansivity above 600° C.
2. The magnetic transformation point is not appreciably affected by a variation in the nitrogen content of the weld.
3. The transformational characteristics of various types of weld metal are so altered by a severe hydrogen anneal that they become similar to those of pure iron.

[11] For the determination of the magnetic transformation points the following set-up was used: The sample ⅛-in. x 6-in. diam. with a thermocouple spot welded to it was placed in a silica tube. Around the silica tube 60 turns of nichrome wire 32 mil. in diam. were wound as search coil. The silica tube with sample was placed in a tube furnace 2 in. in diam. The nichrome furnace winding was used for heating and for creating the magnetic field.

Why Ductility of Welds Is Important in Welded Pressure Vessels

By **E. R. FISH**

+This paper will be presented at a Symposium in Ductility to be held during the Annual Meeting of the American Welding Society, April 28, New York. Mr. E. R. Fish is Chief Engineer, of the Boiler Division, The Hartford Steam Boiler Inspection and Insurance Company.

FOR MANY years high grade low-carbon rolled steel, free from those elements that cause hot or cold shortness or brittleness, has been recognized and accepted as the proper material for the construction of pressure vessels. This practice is not so much the result of theoretical consideration as it is of the evidence of long practice.

Cast iron and high carbon rolled steels, which have low elongation are very little used for pressure containers, the failure of which might cause serious personal injuries or property damage, having been long since practically discarded, and their use prohibited by authoritative rules. This was because of the undoubted ability of the material with good elongation, say, on the order of 20–30% in 8 in. to withstand, firstly, the fabricating processes and secondly the effects incident to long time use.

It is practically impossible to so construct a vessel of any sort that the stresses are of the exact magnitude and distribution the designer intended. Concentration of stresses, the nature of which may not be thoroughly appreciated and which are not infrequently entirely ignored, may and often do raise the unit stress of some part above the elastic limit. When this occurs in a suitable material there is at once a slight stretching and a redistribution of stress that safeguards the integrity of the structure. If the yield point is well below the ultimate strength of the material this readjustment is readily made and is highly advantageous, but in brittle material, that is, where the yield point is near the ultimate, a fracture may easily be started if, indeed, immediate failure does not occur. Failures of cast iron vessels under pressure are too numerous and familiar to require specific examples as proof.

Small cracks are very often the points at which stresses are much greater than in the solid plate and which gradually extend to ultimate failure. To this phenomenon has been traced serious cracks in many riveted seams and was the reason for prohibiting the use of punched rivet holes unless finished by machining out the hole so as to remove the injured metal.

A vast amount of fusion welding has been done in the past 20 or 25 years and many pressure vessels have been so fabricated. The insurance companies know to their financial cost, that many of these have failed. Such vessels have, therefore, not been acceptable for insurance and have quite consistently been refused coverage.

There are few, if any, welding shops which have not had exasperating and costly experiences of welded work cracking unexpectedly and mysteriously, either while in process of manufacture or just after the job had been completed. Cast iron is extremely difficult to weld at all but is peculiarly susceptible to cracking during or after the welding process. The basic cause of all this difficulty is the lack of ability of the metal to adjust itself to the high localized stresses due to temperature differentials.

Since welding must necessarily be done by the application of very high temperatures locally applied it is a practical impossibility to avoid the large so-called "locked up stresses" that result. Unless all the material subject to stress is such that it can stretch without injury there is strong probability of cracks developing. This includes the weld metal as well as the base metal. These stresses due to highly heating metal contiguous to relatively cold metal are present not only in the weld metal, but they are existent also in the adjoining base metal. Consequently there are pulls in various but indeterminate directions, the magnitudes of which are indeterminate as well. These may be called fabricating stresses and have been the cause of the shop failures before referred to. These should preferably be eliminated before a vessel is put to its intended use. However, in the case of the lighter walled structures there does not seem to be as great need for this relief as with heavier metal, due probably to the more even distribution throughout the thickness and the easier stretching of the metal when of the proper physical quality. All of the adverse effects of temperature differences are at least minimized by ductile metal.

From all the foregoing was evolved the principle that "the weld metal should have physical characteristics which closely approach those of the base metal" and until the attainment of that end could be assured the A. S. M. E. Boiler Code Committee, the insurance companies and conservative users refused to recognize fusion welding as a method for constructing boilers or pressure vessels except to a very limited extent. There is no doubt that this persistent refusal stimulated great activity on the part of those interested in this method of construction to investigate the shortcomings of the process. The ensuing research is reflected in what may be called "modern welding," one of the outstanding characteristics of which is ductility of the weld metal—the ability to stretch a reasonable amount without cracking or breaking.

The technique which must be followed and the material which is suited to the production of these modern welds together with the skill of the operators contribute to the absence of gas pockets, slag inclusions or lack of fusion; in short, sound welds are much more certain than when otherwise made. In other words, mechanically perfect work is more likely to accompany the physical characteristics when the principle hereinbefore stated is observed than when the welding is not done to a specified standard.

Imperfections in the weld provide the points for those stress concentrations from which possible cracks may develop, especially if the necessary ductility is lacking. After a more or less extended term of service these are likely to grow to dangerous proportions and to ultimately fail, because the effect of the small changes in shape that are constantly taking place are cumulative over considerable periods of time.

This subject of ductility of welds is a controversial one as there are many who believe that the arguments presented are more theoretical than practical. Some men believe that a welded joint which is stiff and much stronger in tension than the base metal, is perfectly dependable, irrespective of the other physical qualities, but the great weight of opinion lies the other way. This statement is based on the answer to numerous inquiries made of large manufacturers and many discussions with those familiar with the art.

The writer is thoroughly of the opinion that ductility in weld metal is highly desirable, if indeed it is not absolutely necessary to insure welds, the integrity of which can be depended on with reasonable certainty.

At least one company is now beginning a series of tests of various kinds to determine, if possible, the actual value of greater ductility and the results of lower values under representative operating conditions. There is still a long way to go and much to be definitely determined in all phases of fusion welding, by intelligent investigation before indubitably definite conclusions can be reached. Those whose interests lie in the welding field should persistently follow a well-ordered plan of research and not hesitate to give the results to the world. The whole industry will be benefited and the general confidence in and acceptance of welded construction be thereby greatly enhanced.

New Aspects in Pipe Welding

By WILLARD P. CURLEY

✦This paper will be presented during the Annual Meeting of the American Welding Society, April 27th to 29th, New York, by Willard P. Curley of Tube Turns, Inc.

THE WELDING of pipe, both by the oxyacetylene and electric arc processes, has been the subject of considerable discussion in the past few years. Despite prevailing conditions, progress is being made in many of the major piping fields and a more general use of the method may be found thoroughout the industry.

It is interesting to trace briefly the various cycles through which the application of welding pipe has passed. The first step consisted merely of changing over the lines joints from the threaded to the welded type. The advantage of this method in cutting down leakage was so successful that gas distributing companies were quick to standardize on this construction in mains and service connections.

Next, we find a gradual replacing of threaded elbows by use of the miter or stove pipe weld. This type of construction made further elimination of leakage possible and provided some advantages in flexibility of the piping system over the older methods. Short segments of pipe were cut after marking by template, and were then welded into the line to give proper direction change. For low pressures and velocities often just one forty-five degree cut was made across the pipe, then one end was turned over and the ninety degree turn was made. Where higher efficiencies were required in the turn, often as many as five or six segments were used to secure better flow characteristics. Plain slip-over type flanges were used, welded front and back where flanged connections were required. Branch connections were made by cutting the hole in the main, then shaping the end of the

branch to fit, after which the joint was welded. Although superior to the former methods, this type of welded constructon was somewhat of a makeshift and lacked in many details the advantages which were later to become available through a more careful study of the application of welding to piping installations.

Next came the introduction of fittings, designed for pipe welding, and shortly thereafter the high hub welding neck flange was made available. Intensive research and promotional work by the manufacturers of welding equipment and development of proper standards by the Piping Contractors National Association have contributed largely to the rapid progress made by welding in the various piping fields in the last three years. It is now possible for the engineer to draw up specifications and designs covering the welding piping installation in much the same way as was formerly used to cover the threaded and flanged installation, with assurance that if properly carried out, such systems will give to the owner the utmost in piping service.

Before considering some of the new aspects in pipe welding, it would be well to review briefly the progress by industries.

The past year has witnessed some let-up in the building of long transmission lines for oil, gas and gasoline. A number of long cross-country lines were completed during the year, and considerable mileage of gathering lines and short transmission lines were laid. Welding of these lines continues to be recognized as the logical method when first cost and operating efficiency are fully considered.

Other branches of the oil and gas industry continue to apply the welding process in piping although the curtailing of new construction has had some bearing upon the progress made. Some major refining companies continue to emphasize the fire hazard when the welding process is used near equipment in operation. The attitude of one large company to this question is worthy of report.

"Piping is welded from stem to stern. This includes pump house connections as well as outside lines. By careful procedure lines are properly blanked off and the air is cleared by means of suitable equipment so that welding can be done with safety. Some very unique methods are used to provide safe operating conditions.

"Although the capacity of this plant has more than tripled in the past ten years, the maintenance work is well taken care of by a group of 20 fitters and 12 welders, as against some 60 fitters engaged in maintenance work 10 years ago. As rapidly as possible old types of construction are replaced with welded joints."

A large part of the piping in the present-day refinery carries either oil or vapor at extremely high pressures and temperatures. The additional margin of safety resulting when lines carrying such inflammable materials are welded should unquestionably make this type of construction preferable in new work. It is logical to assume that these same qualifications make the welded pipe joint applicable to maintenance work in oil refinery piping, although obviously some care must be used to see that operating conditions are such that the danger of fire is eliminated.

The situation in the low pressure heating field is unusual. Like any progressive step, pipe welding in this industry has been confined largely to enterprising contractors, interested in giving to the owner the most efficient installation embodying all the latest developments in the piping field. The tremendous decrease in construction of a private or semi-private nature has been keenly felt by these organizations.

Public work, including projects erected for state and federal governmental departments, now predominates and the desire on the part of these agencies to avoid limitation in specifications has to some extent delayed a more general application of pipe welding in such projects.

The distribution of steam from central stations is becoming more general, particularly in congested areas. The piping of this steam involves problems a great deal similar to those involved in the distribution of natural and manufactured gas, with the result that welding of practically all pipe joints is now quite general. In a sense this field is outstanding in that valves, slip type expansion joints and other fittings, designed especially for welding, have been developed and these installations are in many cases practically 100% welded.

The use of special corrosion retarding materials in the chemical field has placed before the manufacturers of welding equipment the problem of perfecting materials and welding technique which would give satisfactory welds in alloys of this nature. Except in isolated cases of an unusual nature, the difficulties have been overcome.

Refrigeration piping requires to a high degree those characteristics which welding gives to piping. The comparatively high pressures demand joints that are tight. While some progress has been made, a more general application of pipe welding in this field should be sought.

Considerable progress has been made by those interested in preparing a suitable Welding Code to cover high pressure piping. In the high pressure steam field several outstanding installations were completed during the past year. One in particular erected for a large utility in one of the Southern States was designed for 600 lb. at 720° F. The plant is now operating at 448-lb. pressure. Vee-type butt welded joints in the main steam piping carry the full steam pressure.

The test upon completing the job as well as the operation of the plant today indicate that the installation is extremely satisfactory in every respect. Both shop and field welding were used.

A similar installation was also completed where operating conditions were almost identical with those outlined. The increasing number of projects in which welded pipe joints, without reinforcement, are carrying the full boiler pressure is gradually overcoming the reluctance to accept welding in high pressure installations. There exists some disagreement as to the relative merit of the strap or sleeve reinforced joint in higher pressure service. That point will be discussed elsewhere, in connection with the pressure piping code. It may be noted here that, generally speaking, engineers seem to look upon the reinforced weld with suspicion. The objection to built-in stresses in the reinforced joint is questionable but it should be given consideration. Of some importance, particularly in these days and times, is the apparent high cost of this type of reinforced joint which seemingly has little merit over the vee-type butt welded circumferential joint.

Now to consider the new aspects of the Pipe Welding Field. A most important problem now confronting the welding industry in the piping field is the necessity of developing further those characteristics which tend toward greater economies both in first cost and maintenance to the owner, without sacrificing in any sense the outstanding advantages of the welded installation. At present considerable work has been done along this line but, generally speaking, this has concentrated around the actual weld itself in an effort to lower time consumed by the operator in making the weld. The competitive conditions thus created within the industry itself have tended to retard progress in pipe welding, and the inclination has been to disregard the tremendous future possibilities in this wide field.

In changing over from the cast to the welded plate construction in various pieces of equipment the design of the new product in many cases is entirely new. Previously, it was pointed out that in the pipe welding field such has not been the case. We have to a large extent merely substituted the welded joint for the screwed or flanged type. To present its fullest advantages, welded piping should be designed and erected, in accordance with past practice, only so far as these former methods lend themselves toward economical installation costs and efficient operation.

A discussion of the subject readily divides itself into two major headings—first, new installations, and, second, maintenance of the existing piping system.

To take full advantage of welding as it applies to piping, we should begin at the bottom. Piping standards arrived at with the use of the threaded joint in mind, obviously are not suitable for the welded joint, if, as we say, 100% of the efficiency of the base metal is attainable. The use of light gage tubing, practiced for some time in Germany and quite generally used in welded low pressure marine piping, is obviously a step in the right direction.

Along with the creation of proper pipe standards to apply when piping is welded, depending upon the internal pressure, corrosion and other important features of the average piping installation, we must have, also, new designs in fittings such as flanges, ells, tees, valves, hangers, etc.

These standards should be worked out by the industry, in conjunction with material manufacturers, the various engineering societies and piping contractor organizations. If these standards are properly carried out, we should revise somewhat existing ideas regarding the pertinent feature in any piping installation such as—design and layout; pressure loss; expansion and contraction.

In laying out such a welded installation, full consideration should be given to the weight, which would decrease considerably below existing standards. It is well to recall here that welding of pipe even with existing standards has already made decided reductions in the total weight of the system possible. As an example we might mention a steam header laid out for flanged cast steel with an estimated total weight of 17,700 lb., which was changed over to a welded design with a resulting reduction in weight of 7200 lb., or 40%.

The absence of shoulders in line joints and in elbows, and the superior flow characteristics of branch outlet fittings for welding give less pressure loss through the welded piping installation. Abutting pipe ends in line joints and also joints at the ell cut down on friction loss, particularly when these ells have uniform wall thickness, and facilitate both internal and external alignment.

Recently a number of interesting tests have been made with ells of various radii to determine the effect of radius on pressure loss. The results of these test, made in conjunction with the Government Laboratories will be available in the near future.

Expansion of the welded piping installation, due to the absence of threaded connections, presents a somewhat different problem than the former method. Erection of offsets and loops in the field make it possible to take full advantage of the flexibility of the welding process. The use of the square welded loop as a means to provide flexibility in the piping system has been clearly demonstrated by the number of such installations in satisfactory operation throughout the country.

Many other characteristics such as reduced insulating costs, and other features already well known to us now, would tend to make these new standards just so much more desirable in the welding of pipe generally.

So much for the discussion of pipe welding as it applies to new installations erected under the suggested standards.

Maintenance of the welded installation shows a decided economy over the upkeep and repairs necessary to maintain the piping erected by former methods. Likewise, welding when used to replace other types of pipe joints usually presents many advantages. The experience of one outstanding company is worthy of note in maintenance work, and it demonstrates the advisability of using pipe of a thickness sufficient to do the job at hand, if the real economy of welded piping is to be secured.

Each sketch showing the dimensions, and operating conditions of a replacement section of piping, is carefully studied. Wherever possible, light wall pipe in the closest size and thickness obtainable is used in low pressure work. The use of flanges and other fittings made to existing standards to some extent offset the saving. The practice has been found very much worth while and will probably be included more extensively in the future on both maintenance and major piping installations.

Ductility: What Is Its Significance? How Test for It?

By H. F. MOORE

+This paper will be presented at a Symposium on Ductility to be held during the Annual Meeting of the American Welding Society, April 28th, New York. Prof. H. F. Moore is Research Professor of Engineering Materials, University of Illinois.

AT THE OUTSET it should be stated that this brief paper offers no solution of the problem indicated by its title. In it is attempted to outline a problem important to structural engineers and machine designers, and of especial importance to designers of welded joints in metals.

In all the formulas for strength of structural members, whether in text-books, handbooks, or building codes there will be found no terms depended on the ductility of the material. In tables of allowable working stresses there is no evidence of consideration of ductility, only of strength. Perhaps in a few technical papers written by adventurers in the field of strength of materials there may be found suggestions that quantitative consideration be given to ductility as well as to strength in assigning values for constants in working formulas, but these rare suggestions have as yet borne little fruit.

However, very soon after iron and steel came to be used as structural materials, the need of giving some consideration to ductility was forced on the notice of the structural engineer through the emphatic but costly teaching of failures in service of beams and truss members made of brittle metal, especially of cast iron. The fall of the Dee bridge at Chester, England, the failure of the Tay bridge, and the fall of the Pemberton Mills in Lawrence, Massachusetts, all were vivid object lessons

which soon caused the structural engineer to refuse to use iron or steel for tensile or flexural structural members unless it was proved by test to be capable of withstanding a considerable amount of bending or stretching without fracture. This "pass or fail" method of recognizing the need of ductility is still the only one used to any appreciable extent.

If structural parts were so perfectly shaped that in erection they could be fitted together without any cold-bending of beams or cold-stretching of rivet and bolt holes, and if it could be surely known that the structure would never be subjected to any loads, accidental or otherwise, above those for which it was designed, then there would be no need of worrying about ductility. To a very large extent this state of affairs is true for springs. In a spring a stop usually limits the stress which can be developed, and its connections to other parts are quite flexible. Strength is the prime requisite for spring steel; there is little need to worry about ductility. Obviously, however, for most structural parts the case is quite different, and ductility is necessary as an insurance against fracture under occasional overloads, and against fracture under adjustments necessary in erection.

All our mechanics of materials has been developed with especial reference to the design of structures made of steel, and subjected to only a few changes or repetitions of load. For such structures there have been developed fairly satisfactory tests for ductility, cold-bending tests, measurement of elongation and reduction after fracture.

The study of the effect of oft-repeated stress has been made necessary primarily in connection with the design of machinery, but what with tall buildings subjected to varying wind loads, elevated railway structures, pressure vessels, and pipes subjected to water hammer the problem of behavior under repeated stress is fast becoming important in the structural field. Under repeated stress (above a limiting value) the ductility of a metal seems to become gradually exhausted, or perhaps it is more accurate to say it becomes unavailable, because at minute defects in the metal there are developed high stresses over minute areas, and minute cracks start and spread, and the ductility of the metal even at a slight distance from a crack is not called into play at all. Metals differ widely in their sensitivity or "tenderness" to this cracking tendency, and the ordinary cold-bend or elongation tests do not give much idea of this "tenderness." Judging by the results of tests of metal specimens in which small nicks have been cut, pure metals and fine grained metals seem to be especially susceptible to this tendency to crack under repeated stress. Heat-treated metals with fine grain structure are not, of course, actually weaker than coarse-grained metals under repeated stress, but they seem to be more easily injured by scratches, notches, and screw threads. Oddly enough a nick caused by a blunt chisel seems to do much less damage than the same sized nick cut with a sharp tool.

The use of the metallurgical microscope to examine fatigue cracks in metal throws some light on this question of "tenderness." In a specimen of ordinary structural steel the crystalline grains are of two kinds, pure iron (ferrite) and grains containing iron carbide (pearlite). They are fairly large, and for some distance on either side of the crack the ferrite grains show signs of damage, lines showing where thin laminae of the ferrite grains have slipped over each other. Considerable energy must have been expended in doing this damage as well as in forming the crack. In the case of heat-treated alloy steel the grains are much finer, and very little evidence of slipping or other damage can be seen outside the line of the crack. In the structural steel it seems as if the metal near the crack were able to get help from metal several grains away in resisting the spread of the crack, while in the heat-treated alloy steel the spread of the crack was not hindered by any resistance of grains outside the immediate vicinity of the crack. In the case of the pure metals the grains are large, and there is a considerable distribution of damage among grains adjacent to the crack, but the grains are all alike, and are so large that a crack can get quite a start within a single grain and is less hindered in its spread by running against stronger grains than is the case for the structural steel, with its two kinds of grains.

The ordinary cold-bend and elongation tests are not very effective as tests to insure metal which shall be resistant to starting cracks at points of localized high stress under repeated loading. For example, duralumin, some nickel-copper alloys, and heat-treated alloy steel all rate as ductile metals under such tests, yet they are all "tender," and spreading cracks start in them readily. The terms "dynamic ductility," "crackless plasticity" and "body" have all been suggested to denote this resistance to spreading cracks. The term "crackless plasticity" will be used in this paper.

Fatigue tests of notched or scratched specimens have been suggested as tests for "crackless plasticity." Such tests are time-consuming, and the exact shape of the notch or scratch plays so important a part that it would be a difficult test to standardize. Impact tests of notched bars have not as yet shown any correlation with this property of crackless plasticity. The test proposed by Foeppl and Von Heydekamp is worthy of study, although its value has yet to be established. The test consists in a measurement of the rate of dying out of vibrations in a specimen of metal, acting as a sort of tuning fork. In metal for which the damping of vibration is rapid crackless plasticity is supposed to be high.

Ordinary ductility may be regarded as insurance against fracture under occasional overloads, and crackless plasticity may be regarded as insurance against the formation under repetitions of normal loads of a spreading crack from some point of high localized stress. Neither accidental overloads nor high localized stress at notches, scratches and small holes can be avoided in structural members, and it takes only one spreading crack to cause complete failure of a structural member, although the possibility of detecting such a crack before it has spread to complete failure is generally higher in structural parts than in machine parts.

The necessity for considering ductility has become especially important in connection with welding. Although we have not always realized it, riveted fastenings have a good deal of inelastic adjustability. It is a very unusual riveted joint which can be regarded as a perfectly elastic connection. It is highly necessary that welded joints, including the weld metal, the base metal and the metal in the junction zone, should be ductile. It is necessary that the metal should have ordinary ductility for steady loads and to withstand the strains of erection, and as the use of welding is extended to pressure vessels, tall buildings, railway structures and some machine parts, it is becoming increasingly necessary that welds should have "crackless plasticity."

Ductility in Arc Welds with Some Reference to Strength Values

By CHAS. H. JENNINGS

†This paper will be presented at a Symposium on Ductility to be held during the Annual Meeting of the American Welding Society, April 28th, New York. Mr. C. H. Jennings is connected with the Research Laboratories of the Westinghouse Electric & Manufacturing Company.

Introduction

ARC WELDS, the same as all metals, have certain physical properties peculiar to themselves which are dependent upon the combination of existing variables under which they are made. The evaluation and interpretation of these properties, however, is sometimes a difficult problem.

The tensile strength, yield point and fatigue strength of welds are physical properties that are easily determined and directly applicable to the design of structures. The impact strength and ductility of metals are physical properties that are determined by certain fixed methods and are not directly applicable in the design of engineering articles. The knowledge that a weld has an impact value of 40 ft.-lb. or an elongation of 30% by the free bend test is not sufficient data for determining design loads.

These latter physical properties, however, particularly ductility, have a definite value and place in the design of welded articles. It is the purpose of this paper, therefore, to discuss the different methods of determining the ductility of welds and to compare these results with the ductility values of other materials.

Ductility Determination

It is the property of ductility that allows metals to be drawn into wires, and to be bent, twisted and spun into various shapes. It is the lack of ductility in such metals as cast iron that causes them to fracture suddenly with practically no change in cross-sectional shape when severely stressed. In the following discussion, therefore, ductility will be referred to as the ability of a metal to stretch and reduce in cross-section without fracturing.

In general, the evaluation of the ductility of metals is based upon certain phenomena occurring during the process of testing them for static strength. In addition to the above, special bend tests are also used for ductility determinations on certain clauses of materials. This type of test will be discussed in connection with welds.

In order to clearly understand how ductility is evaluated, it is necessary to briefly describe what occurs during a tensile test of a metal. Figure 1A shows a typical stress strain diagram of hot-rolled low-carbon steel, while Fig. 1B shows a typical stress strain diagram of a brittle material.

Considering first a ductile metal and referring to Fig. 1, the material acts as an elastic body to point A, which is called the proportional limit. Between points A and B the stress ceases to be proportional to the strain and the curve assumes a slightly decreased slope. At point "B" a sudden change known as yielding occurs in the metal and it stretches to point "C" with no increase in stress. In some cases, the stress will even fall off a small amount as shown in Fig. 1A. At point "C," the stress again starts to build up as the specimen elongates. This continues to point "D," which is known as the ultimate strength.

During the process of stressing the specimen to its ultimate strength, it has uniformly elongated and decreased in diameter. A point "D," the specimen begins to neck down at the weakest section and continues to do so until failure occurs at some point, "E."

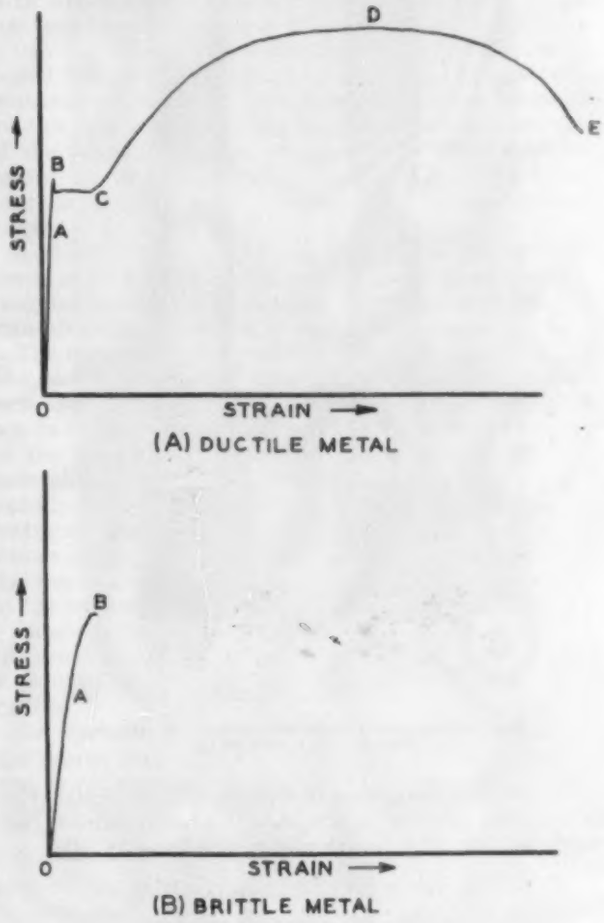


FIG. 1 :- TYPICAL STRESS-STRAIN CURVES OF DUCTILE AND BRITTLE METALS

For brittle materials (see Fig. 1B) the elastic region is from "O" to "A" and the plastic region from "A" to "B." In this material, the same as with ductile metals, the material elongates uniformly to point "B." No necking occurs, however, after the ultimate strength is reached and the specimen fractures suddenly with practically no decrease in load before failure. Figure 2 shows typical fractured specimens of ductile and brittle materials.

The ductility of a material as obtained from tensile specimens is based upon the elongation resulting from plastic deformation and necking and upon the reduced area of the section where failure occurred in the necked portion. The greater the amount of necking and yielding, the greater the per cent elongation and reduction of area, and the greater the ductility.

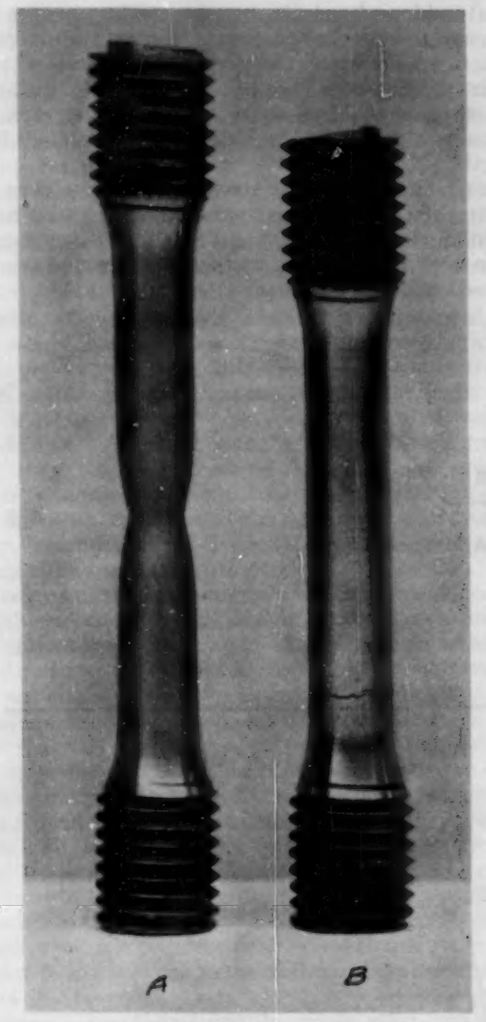


Fig. 2—Fractured Tensile Specimens. *A.* Ductile Metal. *B.* Brittle Metal

The per cent elongation of a material is determined by dividing the increase in length of a predetermined gage length by that gage length and multiplying by 100.

$$\frac{(L + e) - L}{L} \times 100 = \% \text{ elongation in } L \text{ inches}$$

where L = original gage length
e = total measured elongation over gage length of L inches

Because the elongation of a test specimen is not uniform over the entire gage length, but concentrated primarily at the point of necking, the per cent elongation obtained is dependent upon the gage length used. This variation in per cent elongation is illustrated by the following test results on hot-rolled low-carbon steel plate.

Gage Length	% Elongation
2 in.	43.5
1 in.	64.0
1/2 in.	86.0

In addition to the choice of gage length, the shape of the test specimen also has an important effect upon the per cent elongation obtained. Short specimens, or ones with sharp or sudden discontinuities, restrict the freedom of the specimen to neck and consequently reduce the elongation values obtained. Tests made on two series of specimens, on series with a reduced section 2 in. long and the other series with a reduced section formed by a continuous 2 in. radius (zero parallel section) gave the following results:

Type of Spec.	% Elong. 2 in.	% Elong. 1 in.
2 in. parallel sec.	43.5	64
0 in. parallel sec.	..	45.5

In determining the elongation measurements of brittle materials where no necking occurs, variations in gage length do not cause such large differences in the results obtained.

The per cent reduction of area of a material is determined by dividing the change in cross-sectional area at the fracture by the original cross-sectional area of the specimen and multiplying by 100. Reduction of area measurements are difficult to obtain on rectangular cross sections, consequently they are seldom used on other than round specimens.

In the determination of the reduction of area, the specimen design again has a large influence upon the results obtained. If necking is restricted by the shape of the specimen, the reduction of area values will also be reduced.

It is well to point out that other than affecting the ductility values, the specimen design also has an important effect upon the yield point and ultimate strength values.[1,2]

Ductility of Arc Welds

The determination of the ductility of arc welds may or may not be carried out in a manner similar to that previously described for base materials.

A. *Weld Metal.*—In the investigation of weld metal the most satisfactory method for determining ductility is to machine standard A. S. T. M. 1/2 in. diameter tensile specimens from deposited pads and determine elongation and reduction of area values in the usual manner.[3]

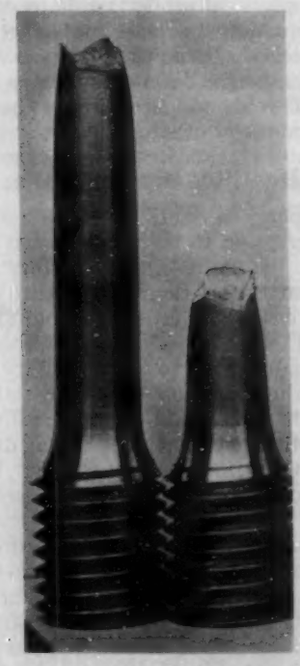


Fig. 3—Fractured Weld Metal Specimen Showing Good Ductility

[1] W. C. Unwin on "The Testing of Materials of Construction," Chap. V, p. 106.
[2] C. W. MacGregor on the "Yield Point of Mild Steel." *Trans. A. S. M. E.*, 53, No. 15, 187 (1931).
[3] "Standard Tests for Welds," *Jl. Am. Welding Society*, 9, No. 10, 67 (1930).

Fig. 4—Fractured Fatigue Specimen Showing Fatigue Cracks Around Holes

Ductility data obtained in this manner are directly comparable with similar data obtained on other materials.

The physical properties of several kinds of weld metal are tabulated in Table I.

Inspection of Table I shows that the yield point and ultimate strength of weld metal deposited with bare wire are higher than the parent metal values, but that the ductility and dynamic properties are lower. The fluxed electrode deposits are superior to the base metal from the standpoint of yield point, ultimate strength and endurance limit. The ductility values in this case, although lower than parent metal figures, are much higher than bare electrode values. Weld metal with an elongation of 24% in 2 inches is considered to be a material of good ductility. A photo of a fractured specimen made of weld metal deposited with these fluxed electrodes is shown in Fig. 3.

The relatively low endurance limit of the bare electrode deposits is primarily the result of the inherent pinholes that appear to always be present in this type of welding. The high fatigue values of the fluxed electrode deposits show that it is possible to obtain weld metal that is stronger in fatigue than hot-rolled low-carbon steel.

The high endurance limit of fluxed electrode welds is partly the result of their soundness and freedom from holes. The presence of small holes in high quality weld metal of this type would greatly lower its endurance limit because of the stress concentrations produced by them.

Figure 4 shows a fatigue fracture of a weld metal specimen containing small gas holes. The effect of the holes is clearly illustrated by the presence of initial fatigue cracks surrounding each of the small holes.

B. *Butt Welds.*—The ductility of butt welds as obtained from tensile specimens is not as easily determined as that of weld metal. Two principal factors responsible for this fact are: the yield point and ultimate strength of the deposited metal are generally higher than the parent metal values, and a butt joint is not a homogeneous structure, but a combination of two different metals.

A third factor in this connection is the characteristic shape of butt welds which makes it desirable to use rectangular specimens. This last factor restricts ductility measurements primarily to elongation values.

The fact that butt welds are composed of weld metal and base metal makes it desirable to measure ductility over short gage length (1 inch is generally used), so as not to have the results affected by elongation occurring in the base metal. Also, because the weld metal is generally stronger than the base metal, failure occurs outside the weld unless the specimen is designed with a restricted section at the weld. As a result, if elongation values are to be taken on butt weld tensile specimens, the specimen design must be such as to cause failure to occur in the weld proper.

Bearing in mind the previous discussion on the effect of the specimen design on the physical properties obtained, it is evident that this fact presents considerable difficulties.

On the basis of the above facts three butt weld tensile specimens were designed as shown in Fig. 5. Photographs of fractured specimens made in accordance with these designs are shown in Fig. 6.

Table I—Physical Properties of Weld Metal

Type of Electrode	Yield Point Lb./Sq. In.	Ultimate Strength Lb./Sq. In.	% Elongation in 2 in.	% Reduction of area	Endurance Limit[a] Lb./Sq. In.	Impact Strength Ft./Lb.
Flex Arc Electrodes (Bare)	44,600	65,000	15.1	21.9	22,000	15.0
General Purpose Fluxed Electrodes	53,200	70,100	24.0	44.0	31,000	49
Base Metal	30,000	55,000	39.0	69.4	27,000	80

[a] Fatigue tests were made on beam type specimens 0.273 in. in diameter at the critical section.

Table II—Physical Properties of 45° Single Vee Butt Welds

Type of Welding Electrode	Type of Tensile Specimen (Fig. 5)	Yield Point Lb./Sq. In.	Ultimate Strength Lb./Sq. In.	Per cent Elongation	Endurance Limit[a] Lb./Sq. In.	Impact Strength Ft./Lb.
Flex Arc (Bare) Electrodes	II	47,140	61,820	11.6[b]	20,100	3.5
General Purpose Fluxed Electrodes	I[d]	45,500	62,700	18.0[b]	27,600	55.5
	II	49,500	71,100	26.0[b]		
	III	60,000	85,000	82.1[c]		

[a] Fatigue tests made on beam specimens 0.273 in. in diameter at the critical section.
[b] Gage length was 1 in.
[c] Gage length was 1/8 in. (Diameter of holes drilled in specimen.)
[d] Failure occurred outside weld and gage marks.

The type 1 specimen (Fig. 5) shows the possibility of high strength weld metal producing failure in the base metal and outside the gage marks. (In this case, the gage length was 1 inch.) The failure in the type 2 specimen occurred in the weld and between the gage marks which were 1 inch apart. The failure in the type 3 specimen also occurred through the weld. In this specimen the diameter of the drilled holes ($^1/_8$ inch) was used as the gage length and the per cent elongation was based upon their extension.

Data obtained from these three types of specimens are given in Table II.

Considering first the results obtained with the fluxed electrodes, it is obvious that the tensile and ductility values obtained from the type I specimen are low and unsatisfactory because failure did not occur in the weld or between the gage marks. The results obtained from the type II specimen appear to be correct when compared with the results on weld metal given in Table I. The results obtained from the type III specimen are obviously high. This is in accordance with the previous discussion on notched test specimens, and ductility evaluations on the basis of short gage lengths.

Comparing the results obtained with the bare and fluxed electrode welds, it is seen that the fluxed electrodes are far superior in every way. The most noticeable differences are the ductility and dynamic properties.

Continuing further with the results obtained with the type II specimen in an effort to correlate the values of butt weld ductility with those obtained on base metal by the usual methods, tests were made on base metal by using specimens of similar design. These data are tabulated in Table III.

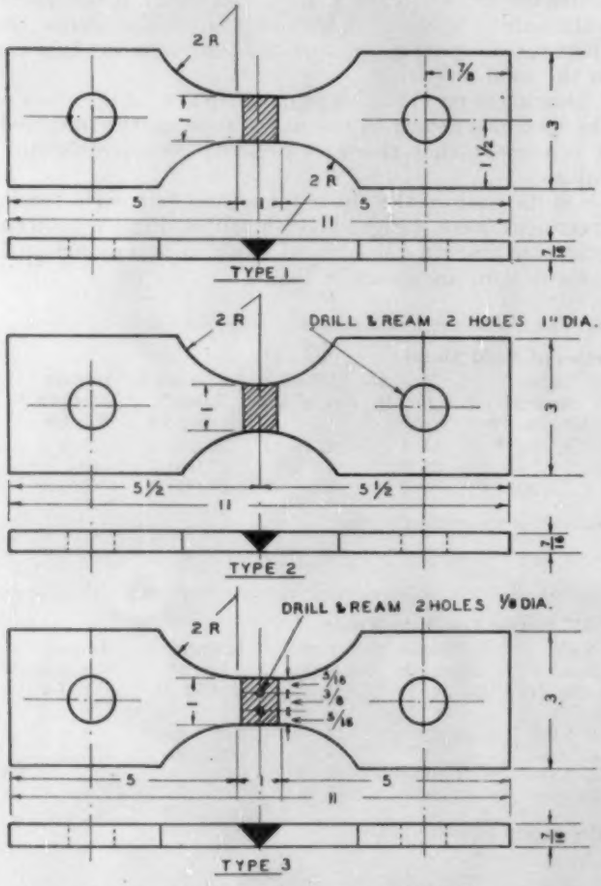


FIG. 5—DESIGNS OF BUTT WELD TENSILE SPECIMENS

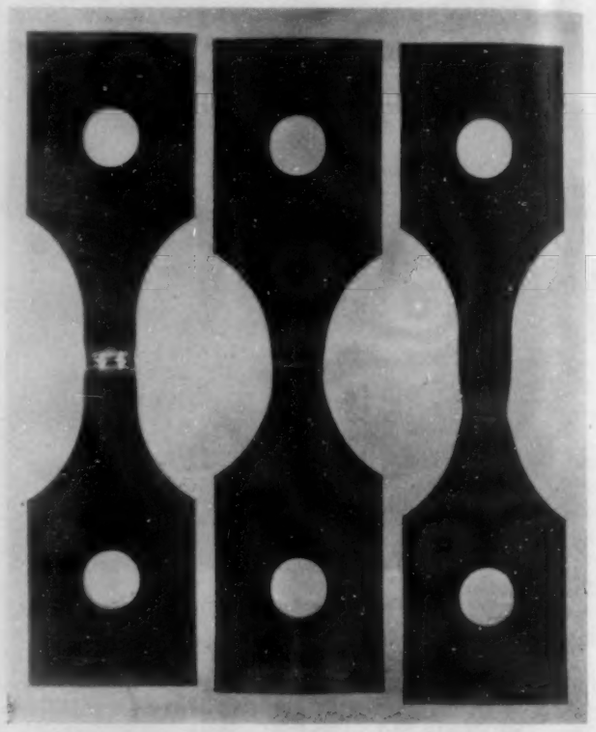


Fig. 6—Fractured Butt Weld Specimens

Table III—Physical Properties of Low Carbon Steel

Type of Specimen	Yield Point Lb./Sq.In.	Ultimate Strength Lb./Sq.In.	% Elong. in 2 In.	% Elong. in 1 In.
Modified Type I (parallel Sec. 2 in. long in place of 1 in.) (Fig. 5)	30,450	53,300	43.5	64.0
Type II (Fig. 5)	31,400	54,600	..	45.5

The yield point and ultimate strength values obtained from the two types of specimens indicate that the reduced section of the type II specimen has practically no effect upon these properties. This is also substantiated by the results obtained from weld metal and butt weld test. (See Tables I and II.)

Regarding the ductility properties, it is seen that the per cent elongation in 1 inch as obtained with the type II specimen is approximately equal to the per cent elongation in 2 inches of the modified type I specimen, which is long enough so as not to effect necking. This conclusion is also substantiated by the data obtained from weld metal and butt welds as given in Tables I and II.

For the particular specimen designs and sizes under consideration, this can be interpreted to mean that a butt weld having an elongation of 26 per cent in 1 inch, as obtained from a specimen of the type 2 design (see Fig. 5), has approximately the same ductility as a material with an elongation of 26 per cent in 2 inches as obtained from a non-restricted type specimen.

Elongation values based upon the extension of holes and extremely short gage lengths (see Table II) are misleading and are not advocated for ductility determinations.

It is apparent from the above discussion that there is a relation between elongation measurements of butt welds and weld metal and base metal if certain proce-

dures are followed. How this relation will vary with different sizes and designs of specimens cannot be predicted at this time. The results obtained in the writer's tests appear promising, however, and this subject will warrant further investigation.

Another very common and satisfactory method of determining the ductility of butt welds is by elongation measurements on bend specimens. The particular type of bend test recommended by the AMERICAN WELDING SOCIETY and the A. S. M. E. Boiler Code is the free bend test.[4]

The free bend test consists of initially bending the ends of a machined specimen (see Fig. 7) containing a butt weld at its mid-section and loading it as a strut by applying loads at the ends. The specimen is bent in this manner until failure occurs in the weld. The method or rate of loading does not affect the test results provided impact loads are not applied.

The determination of the ductility of a weld by the bend test consists of expressing the extension of the outer fibers of the weld in terms of per cent elongation. Within certain limits, the radius of curvature of the bend in the specimen is uniform. Consequently, the fiber elongation is also uniform. As a result, the per cent elongation obtained will be more or less independent of the gage length used. In this connection, Mr. W. B. Miller states that "for consistent results, the gage length should be at least 0.3 in. and not greater than 1.0 in., except in the case of plates $^1/_4$ to $^1/_2$ in. thick. In these cases, the maximum gage length should be not more than twice the plate thickness."[5]

Typical bend test results as obtained on several types of butt welds are tabulated in Table IV and compared with elongation values as obtained from tensile tests.

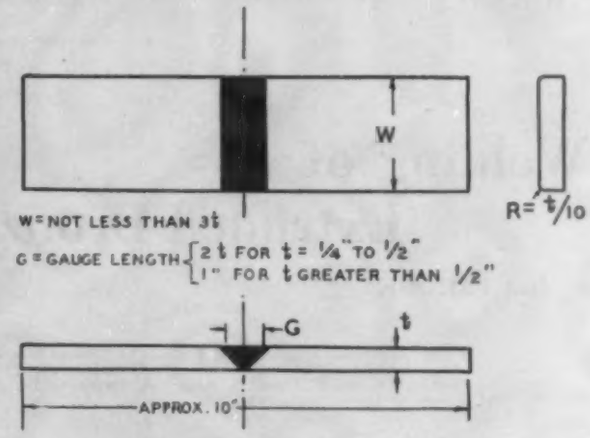
Table IV—Bend Test Elongation Values

Type of Welding Electrodes	% Elongation by Bend Test	% Elongation in 1 In. by Tensile Spec.
Flex Arc (Bare)	16	11.6
General Purpose Fluxed	32	26
Experimental Electrode No. 1	22	24
Experimental Electrode No. 2	36.5	14.0

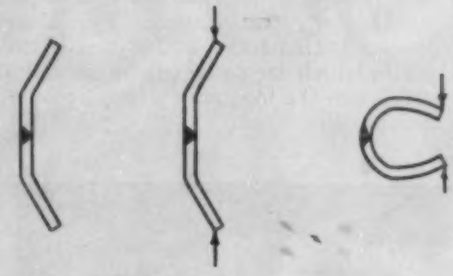
Examination of Table IV reveals the fact that there is no apparent relation between elongation values as obtained by the two methods (tensile and bend). Consequently, bend test data are not directly comparable with ductility data as obtained from tensile specimens. Also, it appears that bend tests do not measure the same properties of ductility that tensile tests do. This conclusion was also obtained by Mr. Miller in his paper on Bend Tests.

This conclusion, however, does not discredit the value of the bend test for determining ductility because if all bend tests are made in the same manner, the results will be directly comparable in themselves. On this basis, therefore, definite standards can be established whereby different classes of welding can be evaluated.

The greatest advantages of the free bend test are its simplicity, cheapness and reliability. One difficulty that has been encountered by the writer, however, is to obtain the maximum bend in the center of the weld when a high ductility weld is being tested. The high yield point and strength of this class of welding causes the maximum bend to occur at the edge of the weld in the parent metal. When this condition occurs, it is almost impossible to produce failure in the weld or between the gage marks. Consequently, the true elongation values are not obtained.



(A) SPECIMEN DESIGN



(B) TESTING PROCEDURE

FIG. 7:-FREE BEND SPECIMEN

Conclusion

The purpose of this paper has been to discuss the various methods of determining weld ductility and to interpret the same. In addition to this, however, complete physical properties of several types of welds have also been discussed.

The principal conclusions that can be drawn from these discussions are as follows:

1. The most satisfactory method of determining ductility properties of weld metal is by elongation and reduction of area values as obtained in the usual manner from standard $^1/_2$-in. diameter A. S. T. M. tensile specimens. These ductility values are directly comparable with similar results obtained on base metals.

2. The ductility of butt welds may be obtained either from tensile tests or bend tests.

A. In the determination of ductility by tensile tests, it is essential that the specimen be properly designed in order to produce failure in the weld without giving erroneous tensile properties. The particular type of specimen used by the author accomplished these items and produced elongation values in one inch which were directly comparable to elongation values obtained in 2 inches on other metals by ordinary methods.

[4] "Standard Tests for Welds," American Bureau of Welding *Bulletin* No. 1; JOURNAL OF THE AMERICAN WELDING SOCIETY 9, No. 10, 67 (1930).
[5] W. B. Miller on "Bend Tests," JOURNAL OF THE AMERICAN WELDING SOCIETY, 9, No. 10, 75 (1930).

B. Ductility values determined by the free bend tests were shown to have no apparent relation to the ductility as obtained from tensile specimens. The fact that elongation values as measured by free bend tests are not comparable to elongation values obtained from tensile specimens does not mean that this method gives unsatisfactory results. As long as the results obtained by this type of test are consistent within themselves, definite standards can be set up whereby different classes of welding can be satisfactorily evaluated.

Welding of Extruded Bronze

By IRA T. HOOK

✦This paper will be presented during the Annual Meeting of the American Welding Society, April 27th to 29th, New York. Mr. Ira T. Hook is Research Engineer for the American Brass Company.

The Extrusion Process

THE extrusion process can be applied to any metal that is sufficiently soft to flow through the die. Metals may be extruded hot or cold, though usually the metal to be extruded is heated because of its being softened at the higher temperatures. Occasionally, however, it is done cold. Thus thin walled tubes of two to three feet in length, which are to be cut up for radiator cores, pencil barrels and the like, are extruded cold from copper or aluminum discs.

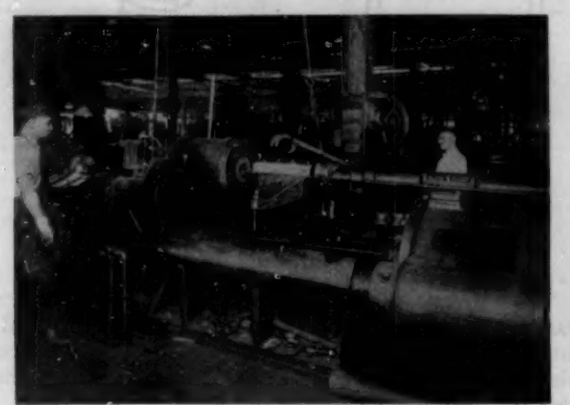


Fig. 1—Extrusion Machine with Hot Slug Ready to Go into Container after Which Latter Will Be Dropped into Line with the Ram and Die

In brief, the extrusion process consists of the insertion of a slug of the extrudable metal into a thick walled cylinder. A closely fitting ram or piston can be pushed through this cylinder from the rear. The extrusion die is secure to the front end of the cylinder. This die, always made of the highest quality of alloy steel, carries the hole or shape which is the exact counterpart of the right section of the extruded shape desired. Thus if extruded rods are wanted, the die will simply have one or more holes of the required diameter, while if extruded angles are to be made, the die will, of course, have an "L"-shaped hole of the same dimensions as the right section of the angle. The pressure piston which forces the metal to flow through the dies is most conveniently operated by hydraulic pressure.

Extrudable Metals

Some metals are commercially extrudable while others are not. Thus high carbon steel is not extrudable because there is no material hard enough with which to make cylinders, pistons and dies to use with it. Again, soft steel and iron are not commercially extrudable because if heated hot enough to make them soft they will stick to the steel dies. Copper can be extruded if the sections are relatively thick, but the pressures required are high and the combined effect of heat and pressure is very severe on the dies.

The two alloy groups of copper which are most readily extrudable are (*a*) those which carry 38 to 45% of zinc, and (*b*) those which carry 5 to 10% of aluminum, the remainder, for the most part, being copper. The first of these falls in the Muntz metal class, which metal was patented in England just 100 years ago. The high percentage of zinc is desired for the reason that such alloys have a considerable proportion of hot-workable beta phase brass. The brasses containing 36% or less of zinc, the remainder copper, are in the alpha phase, and are not very well adapted to hot forging. Beginning with 37% of zinc, the beta phase appears and increases with the zinc content up to about 46% zinc, at which point a third phase, the brittle gamma, begins to appear. The beta brass or Muntz metal is softened by heat without losing its malleability. It, therefore, makes an excellent forging or extruding material. When cold, the beta brass is harder than the alpha though the reverse is true when they are hot. In the case of the aluminum bronze, both the alpha and the beta phases are softened by heat and are readily forgeable or extrudable.

Other Elements

Other elements of interest to the welder, which are more or less frequently used in the extruded metals, may be named as follows:

Tin is a very desirable addition as even in small quantities, $^1/_2$ to $^3/_4$ of 1%, it exerts a profoundly beneficial influence on the hardness, strength and weldability of the alloy without diminishing its extrudability. "Naval Brass" is the best known of the zinc-tin-copper alloys. A considerable tonnage of this extruded material is used in structural shapes, trim and hardware for ships.

Manganese and *iron* are frequently added, manganese in varying proportions from a trace to 1% or more, iron in amounts from $^1/_2$ to $1^1/_2$%. Tin is usually retained in amounts from $^1/_2$ to 1%. This group of alloys are readily extrudable and are generally known under the name "Manganese Bronze." Manganese bronze makes a very valuable welding rod where hardness and wear resistance are desired. The deposited metal from a standard manganese bronze used for welding has a Brinell hardness of approximately 100.

Lead is frequently added to the extruded zinc alloys in which it remains largely as finely distributed metallic lead. In this form it makes the alloy easy to machine—the primary reason for introducing it. It has a slight effect on color, helping to tone out the greenish cast and aiding in bringing out the richer bronze shades. "Ana-

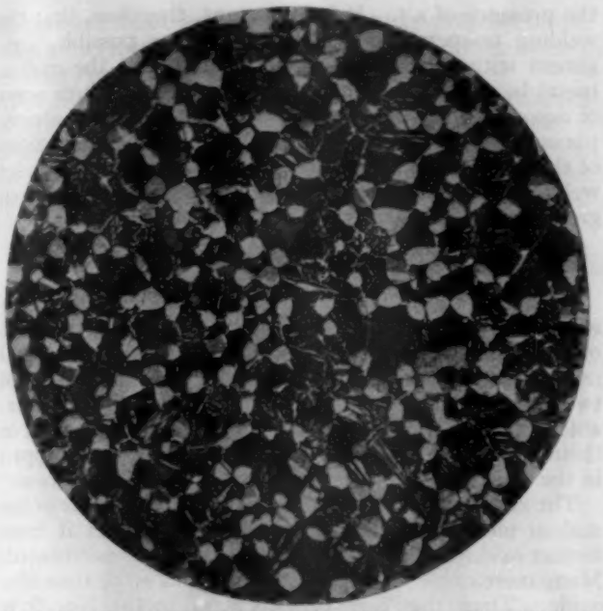


Fig. 2—Beta Brass. The Light Areas Are Alpha Phase Brass, While the Dark Areas Are the Beta Phase Brass

conda Architectural Bronze" is perhaps the best known and most widely used of the leaded extruded bronzes. Lead has a bad effect on the weldability as we shall see in a moment.

A new alloy, known as "Extruded Architectural Everdur Metal No. 9," contains, in addition to zinc, small percentages of manganese and silicon which make it an excellent metal for fusion welding.

Iron in amounts approximating 1% is beneficial to either the high zinc extrusion alloy or to the aluminum bronze. It increases the hardness and strength slightly without impairing the workability of the material.

Nickel is an important element, alloying readily with the copper and zinc. "Anaconda Extruded Nickel Silver," containing 8 to 15% of nickel, is a soft-toned white architectural metal. Figure 6 shows an entrance of a Fifth Ave. building made up of this metal. With a comparatively simple design, the architect has obtained a dignity and beauty that is altogether satisfying.

Aluminum.—The aluminum bronzes form a group quite distinct from the above high zinc alloys. No zinc is present in the aluminum bronzes. The 5% aluminum bronze, known as "Anaconda Forging Bronze," makes an excellent alloy for forging purposes. It has a rich gold color and may be welded with Tobin bronze. Figure 7 is an example of the artistic workmanship possible with this metal. Aside from the forging metal, the extruded aluminum bronzes are used more for engineering purposes where a combination of strength and high corrosion resistance is desired than for architectural purposes. They are much more difficult to machine than the leaded architectural bronzes.

While the aluminum bronzes, having 7 to 10% of aluminum with small percentages of other elements, become softened and extrudable at temperatures above 850° C. (1562° F.), at lower temperatures they retain their hardness and non-scaling qualities to a remarkable degree. As valve seats, "Avialite Bronze" has contributed not a little to the long life and steady performance of aviation motors when operated under the grueling conditions of long flights.

With a Brinell hardness of 117 at room temperature, this metal has a hardness of 111 at a low red heat, 575° C. (1067° F.). Under identical conditions, the hardness of manganese bronze will drop from 100 to 65. The resistance to scaling is even more marked—the aluminum bronze remaining clean and bright after long periods at this temperature.

Extrusion vs. Rolling and Drawing

Those familiar with mill processes in a general way only, may well inquire "why not roll the shapes just as structural steel is rolled instead of extruding them?" While there are special sections, as for instance dovetailed sections, which cannot be rolled at all but which are easily and accurately extruded, the answer to the question in general is that rolls are much more costly tools than extrusion dies. Where a limited quantity of a given shape is desired, it is a comparatively easy matter to cut out the required profile of the section in a disc of steel, perhaps 6 in. in diameter x 1 in. thick, slip it into the extrusion machine, and push the required amount of metal through. It would take much longer and cost much more to make a pair of rolls for the same shape. The American Brass Company, for instance, has more than thirty thousand dies, representing as many different shapes and sizes of extruded metal. Figure 3 shows a few of these.

Extruded shapes are frequently given a cold draw through a finishing die of the same shape as the extrusion die. This hardens the metal slightly, straightens and shapes it more exactly than can be done with the metal hot and soft.

Welding Properties

In this discussion we are interested primarily in those properties of extruded metal which affect the welding process. These properties are considered in detail below. The methods of joining extruded shapes vary greatly in different fabricating shops, and the subject is further complicated by the variations in the alloys themselves. This paper, therefore, is to be regarded more in the nature of a progress report than a final word in the welding of extruded metal.

Color.—Since by far the larger part of the extruded metal goes into architectural trim where color is of paramount importance, the welder must take this property into consideration. The richness and artistic perfection of an extruded bronze entrance can be largely spoiled by seams and splotches of weld metal which do not harmonize with the color of the base metal. Sometimes a near color match is worse than a distinct contrast. Thus the usual half-and-half lead-tin solder used on nickel silver, which gives as nearly a color match as can

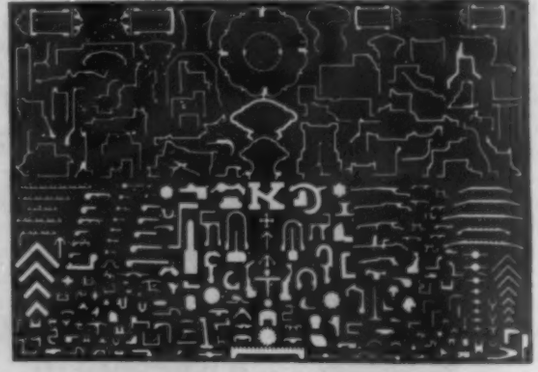


Fig. 3—A Few of the Twenty Thousand or More Shapes and Sizes Extruded by the American Brass Company

be described in words, may yet stick out like the proverbial sore thumb when it appears on a polished surface.

Again, it is not sufficient that the weld metal match the color of the base metal when freshly finished. It must follow the color tone of the base metal whether the exposure be inside or outside. As an illustration, pure tin will match the color of nickel silver fairly well when newly deposited, but holds its color better than the base metal in the weather, becoming more and more of a contrast therewith as the weathering continues.

Some specific notes as to color matches are as follows. By far the larger tonnage extruded metal is in the form of the rich-yellow, leaded "Architectural Bronze." This color also predominates in the extruded brasses, manganese bronzes and free-cutting brasses and bronzes and the aluminum bronzes. In general, a welding rod of the character of manganese bronze or Tobin bronze will match these alloys in color so that only an expert can detect the difference. It will also follow the tone of the base metal on weathering.

Fig. 4—Window Sash, Frame and Casing of Architectural Bronze

In exceptional cases where the color match must be exact, as a seam in the flat surface of a door which is kept polished, strips may be sawed from the base metal and used as welding rods.

The white extruded alloys, which are usually finished in a much softer tone than is observed in plated surfaces or the stainless steels, are matched in color by the silver solders and by nickel-silver welding rods.

Heat Conductivity.—In welding the extruded alloys, this property must be taken into account. Various compositions will have thermal conductivities between 25 and 45% of that of copper, or from two to three times that of low carbon steel. Accordingly, more heat must be used than for steel or Everdur, and usually a longer time is required to bring it up to the welding temperature than is the case with the two metals named.

Hardness and Strength.—While the extruded metals are as a rule used more for their richness and beauty of color and their time-defying stability, they have considerable strength and wear resistance. The tensile strength will vary from 40,000 to 60,000 lb. per sq. in., with a Brinell hardness of 75 to 100. Special mention of the excellent red-hardness of aluminum bronze is given in an earlier paragraph.

Zinc and Lead Volatilization.—In any alloy carrying these elements, the lead and zinc will oxidize when the metal is heated appreciably above its melting point in the presence of air. It is important, therefore, that the welding temperature be kept as low as possible, consistent with satisfactory strength, and that the molten metal be protected from the air. There are three ways of accomplishing this last, (*a*) by a suitable torch atmosphere, (*b*) a suitable flux, and (*c*) a coating of the oxides of the metal itself. The first two will be discussed under welding procedure. The oxide coating should be given greater consideration by the welder than it has.

Metal Oxides

All of the metals used in extrudable alloys will oxidize if heated sufficiently high in the presence of air. Some of these oxides are useful in protecting the molten metal from further oxidization from the air, while in the case of two elements, lead and aluminum, it will be found desirable in the welding operation to prevent the formation of their oxides. The latter two oxides become entrapped in the weld metal, reducing its strength and soundness.

The zinc oxide, if allowed to form on the surface of the molten metal, will in a large measure protect it from further oxidation until the weld metal becomes overheated. Manganese oxide is more effective on this score than zinc oxide. Thus the new architectural metal No. 9 is welded with less oxidation of the zinc than the manganese free shapes.

Welding Method

The *oxyacetylene* torch is the welding tool most commonly employed. The extrudable metals melt at temperatures between 1600° F. and 1800° F., which temperatures are readily developed in the base metal by the oxyacetylene torch. The spent gases perform a useful function in preheating the base metal, compensating in part for the high heat conductivity of the latter. In handling the oxyacetylene torch, a large tip with a soft flame is desired rather than a small tip with a strong blast. The latter type of flame has the effect of breaking up the protective oxide coating, thus exposing the zinc to further oxidation. Moreover, the position of the flame with respect to the white inner cone is extremely important. The latter should never be allowed to touch the work as is done in the welding of steel, but should be held $^3/_8$ in. to $^1/_2$ in. above it. With the torch in this position, the work is heated uniformly and given the maximum blanketing effect of the torch gases.

Some experimenters advocate the use of a lower

Fig. 5—Entrance Grill and Casing of Architectural Bronze

temperature flame such as that of the oxy-propane torch, but after a reasonably exhaustive trial, the writer prefers a soft oxyacetylene flame to the former.

For *silver soldering*, the oxyacetylene flame is preferred to other methods of heating. It is possible to make a silver-soldered connection with a different type of torch, but the oxyacetylene will probably be preferred for speed, minimum warpage and satisfactory performance.

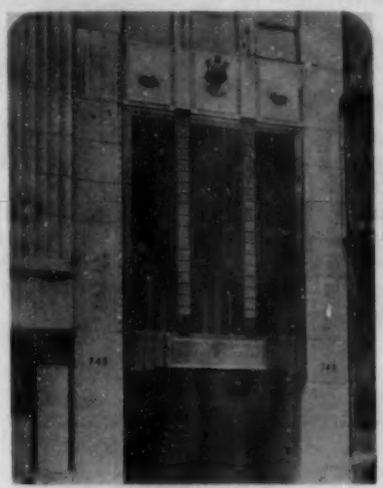


Fig. 6—Entrance of Office Building of Extruded Nickel Silver

For *soft soldering*, it is possible to use the gasoline torch or gas and compressed air. The acetylene-atmospheric air torch is, however, rapidly gaining favor. The latter torch is light and easily handled. It requires only a light tank of acetylene or a small generator and is, therefore, readily portable.

The *metallic arc* has been tried many times without appreciable success. Even when the welding rod itself acts in the electric arc very well as, for instance, a phosphor bronze electrode, the arc causes too great a loss of zinc in the base metal. The high thermal conductivity of the extruded alloys calls for a high current value in the arc which means a considerable volatilization of the zinc with unsound and dirty weld metal.

The *carbon arc* is only slightly more successful than the metallic arc. If the base metal is given a good preheat and the carbon arc is allowed to play on a non-volatile weld metal such as phosphor bronze, reasonably strong connections can be made. It should be understood, however, that phosphor bronze does not give a good color match with any of the extruded metals, and therefore can be used only on the back side of an assembly. The modified heat of an indirect arc is sometimes used.

Resistance spot welding and *resistance seam welding* can many times be used to good advantage. On the other hand, a resistance welding machine designed for use on steel is but poorly adapted for use in extruded metals. The pressure and current control must be much more delicate for the latter than for the former. Moreover, the pressures required are much lighter than are commonly used on steel. In general, resistance welding is more useful on rolled sheets and shapes drawn from same than on extruded shapes. Experimental work is being undertaken to resistance butt weld these materials and results will probably be available at a later date.

Flux

Any good commercial brazing flux will work satisfactorily on the extruded alloys. In general, a flux should be selected that will cling to the hot metal until it melts (not crawl away from the heat as does common borax), spread evenly over the hot metal and flake off the metal as it cools.

Extruded with Wrought and Cast Metals

To bring about certain architectural effects, castings are sometimes used and wrought metal is employed where large panels or flat sheets are desired. Also many times, different combinations of copper alloys are used where color contrasts are desired. Finally, the occasion not infrequently arises where the ornamental, weather-resisting, extruded or wrought bronze is to be attached to or sealed around a structural steel load-carrying member. Each of these combinations presents a different problem to the welder and only general procedures can be given at this time.

Welding from the Back

Many times the hair-line of a closed miter or straight seam is not objectionable, in which case the welding can be done from the back. Such a condition is desirable wherever possible, since no labor is lost in dressing the weld. In making such a weld, no veeing is necessary—the connection being secured and sealed by a reinforcement of Tobin bronze weld metal. The procedure for such a weld would be to make a close fit of the connection. Clamp the two members securely in position. Tack one end of the seam and start the weld at the other end.

It is important that the *base metal be brought up to the welding temperature before the weld metal is deposited*. It is almost impossible to transmit sufficient heat through the molten weld metal to cause a sound connection with the base metal if the latter be cold when the former is first deposited. The base metal should alloy avidly with the weld metal, as the latter is fused from the rod.

Fig. 7—Gate Showing Exquisite Workmanship Possible Using Forging Bronze, Hand Wrought and Welded

It will be found desirable to paint the seam with flux suspended in alcohol before the weld is started. Furthermore, it is important that, once the weld is started, it is finished without a pause. Even the brief interruption occasioned by the dipping of the rod in the flux can and should be avoided. A simple way to pre-flux the rod is to arrange a supply of rods in a single, closely spaced layer, heat with a torch, and sprinkle a good brazing flux on same. The flux under this moderate heat will

become sufficiently gummy to stick to the rods in ample quantity to make dipping unnecessary.

Welding from the Front

In the manufacture of doors, window sashes and similar parts, where hollow sections are to be joined, it is necessary to weld from the front and finish the weld flux with the outside surface. In such a weld, the color match is of prime importance, and the weld metal must be sound and strong. The seam must be open or veed when the parts are clamped for welding. It is generally possible to back the weld with a steel channel or box section. Many times it is possible to spot weld to this backing member in lieu of a clamping jig. The set-up being complete, the weld can be run as described above. The welder can conserve the time of the finishers if he makes a seam with only a slight reinforcement and no hollow places.

Cast ornaments can sometimes be welded from the edges. More frequently they are secured from the back mechanically, or by holes through the background. Castings are usually made of a lower fusing alloy than the extruded or wrought alloys with which they are used. They are also generally high in lead, so that care must be exercised in the welding operations that they be not fused through nor cracked.

Welding Rigid Frames

Perhaps the most difficult problem the welder meets in the fabrication of extruded metals is the attachment of hinges, fastener parts and ornaments to a rigid frame. The welding operation itself is usually simple but the control of the bending and warping occasioned by the welding heat calls for a high degree of skill. It is difficult to remove a wind without marring the work once it is put into a completed frame.

Sweated connections of soft solder are often amply strong for the purpose and the moderate heat required rarely causes distortion. Silver solder used as a welding rod can sometimes be applied with a moderate heat that will not cause appreciable distortion, but a sweated silver soldered connection requires almost as much heat as a fusion weld with its accompanying warp. In planning the work, the lay-out man can often avoid warpage troubles by putting on all attachments before the members of a complete frame are assembled. Any slight distortion caused in a free member can usually be corrected with little effort.

New Development

The new extruded architectural Everdur metal No. 9 is a recent and noteworthy addition to the series of metals available for architectural purposes. It has a deep, rich-gold color, and the character of the metal is such that fusion or autogeneous welding operations are greatly facilitated. Some tensile strength tests on this material, extruded in a $^1/_8$ in. x $1^1/_2$ in. section, are given below. Tests on the same material, after fusion welds were made with the oxyacetylene torch, show the excellent soundness and strength obtainable.

Tensile Strength Lb. per Sq. In.	Per cent Elongation in 2 In.	Remarks
72,600	17.0	Original metal, as extruded
66,300	15.9	Average of four welded samples

Remarks

We realize that this paper is far removed from being a complete solution of the many-sided problem of the welding of extruded metals. However, the topic is a timely one and some points are brought out which may help the fabricators of such material. The rich beauty and everlasting quality of the extruded bronzes with their depth and warmth of color will always have an appeal. With the increasing use of metals in residences as well as in public buildings, the economy obtainable by the use of welded connections will be more and more appreciated.

Ductility in Metal Structures

By C. A. ADAMS

✦This paper will be presented at a Symposium on Ductility to be held during the Annual Meeting of the American Welding Society, April 28th, New York. Prof. C. A. Adams is Director of the American Bureau of Welding and Lawrence Professor of Engineering, Harvard University.

THERE IS hardly any subject of discussion in connection with welded structures that has given rise to so much controversy as that of ductility. This is due, at least in part, to the fact that our knowledge of its importance is exceedingly limited and that most of the discussions have been participated in by those whose views could be labeled "opinions" or "convictions," without much scientific data or even theoretical analysis to back them up.

I shall try, therefore, to confine my present remarks to those phases of the subject about which we know at least a little.

If you take a flat test bar of ductile material and put it in a testing machine, it may have an elongation in 2 inches of 30%, or 0.6 inch, before fracture. Take this same test bar and drill a number of fine holes in a straight transverse line so as to remove one-half of the cross section. Place this test bar in a testing machine and it will elongate probably not more than one-tenth as much as the original bar, although its ultimate tensile strength per unit of net cross section may be just as high or higher than that of the original bar. In other words, the yield before fracture is tremendously reduced not by virtue of any change in the ductility of the material according to ordinary definition, but rather because of a change in form. In fact, if such a pierced bar were located in a structure where a considerable yield was desired, it would behave in a highly undesirable fashion, i.e., as if it were brittle.

It is well known that any sudden change in contour of a structure results in concentrated stresses. For example, if a hole is drilled in the wall of a pressure vessel, the local stress in the vicinity of this hole may be two or three times as great as that in the solid part of the wall.

If the material is ductile and the stress exceeds the yield point in the region of concentration, the resulting readjustment will reduce the original excess of stress in this region, whereas if the material is brittle in this region, a crack may result under conditions which would be quite safe with the more ductile material. This is particularly true in the case of repeated stresses.

The factor of safety required by the A. S. M. E. Boiler Code is 5, not because a real factor of safety of 5 is necessary, but rather to allow for what is sometimes called "secondary" stresses, or for local concentrations of stress. Moreover, the material specified is a low-carbon ductile material. This ductility undoubtedly plays an important part in vessels pierced by openings of various sizes and often by many of these openings.

It is also true that brittle materials are not so resistant to shock.

But, you will say, what has all of this to do with the ductility of welded joints, provided the material between joints is ductile and the welds strong enough to hold? If these conditions obtain, and the weld is homogeneous and free from defects, such as blowholes or slag inclusions of appreciable size, it is my opinion that for many types of structure high ductility is not essential. In fact, many steel buildings have been erected and are now in service where nothing but bare electrode metallic arc welding was employed and where the welds were undoubtedly of very low ductility. On the other hand, there are many structures where the welding process itself introduces local stresses of very considerable magnitude and if, as occasionally happens in the best-regulated families, a blowhole or slag inclusion happens to occur at a critical location, failure may readily occur under some unusual stress, shock or under normal stress if repeated enough times.

In order to relieve locked-up stresses incident to the welding process, it is customary to peen each layer, but if the metal is not reasonably ductile, this peening process itself may result in local cracks—in some cases so deep that the subsequent layer of weld metal will not fuse through their depth.

In the above analysis, I have intentionally avoided quantitative statements, but it should be remembered that we are dealing with a very complicated subject from the analytical point of view—in fact, one that cannot be dealt with quantitatively with the knowledge at present available, particularly when we are dealing with the temperatures involved in fusion welding.

For example, we do not know enough to state positively that a ductility of 15% as measured by bend tests is not sufficient to guard against the dangers referred to above, although we are pretty sure that a similar ductility of 10% or less is unsafe for many structures.

It is entirely possible that a sufficiently comprehensive piece of research work would reduce our knowledge in this field to a much more satisfactory and quantitative basis and it is to be hoped that some such investigation can be undertaken in the not distant future. It will probably require, however, some new type of apparatus or testing equipment and considerable ingenuity in devising tests which will cover the ground and simulate with sufficient accuracy the conditions of and the types of stress met with in practice.

Ductility and Penetration—Two Fallacies

By C. J. HOLSLAG

†This paper will be presented at a Symposium on Ductility to be held during the Annual Meeting of the American Welding Society, April 28th, New York. Mr. C. J. Holslag is connected with the Electric Arc Cutting and Welding Co.

DUCTILITY greater than that of the parent metal would ruin welding but luckily it can be obtained only in advertisements. Penetration also is fortunately an attribute of no one machine. In arc welding, ductility equal to the parent metal can only be attained in test pieces where it does no harm. To show the harm in structural work, imagine two pieces of wood joined by an equal section of rubber. On any kind of a load all the strain and stresses would come on the rubber—the wood would never break, deform or do anything except transfer the load to the rubber. The rubber would gradually age and there would be no conceivable end except that it would be in the rubber joint. Now, if we joined two pieces of steel with a weld that was more ductile than the steel itself, the same thing would occur, namely, all deformation would come in the weld and the weld would not be able to withstand the stresses such as the parent metal and, naturally, would be bound to break. The future of welding would then be in the past.

We believe it is about time the public learned the truth about welding and the art is just about old enough to be acquainted with the fact that there is no Santa Claus.

Welding is now twenty-four years old and it is about time the fact was recognized that an arc weld is porous, always has been and always will be. All steel castings are porous unless centrifugally made and then they get porous in a large hole in the center. Rolled or forged plates have these pores flattened out but the weld is cast porous and generally left that way. We have had as much experience as anyone and ours have holes in the deposit. Some of the large steel companies keep men on the job whose duty it is to withhold from the public that all steel is porous, although it is full of gas bubbles and in the case of cast steel, the holes sometimes are as big as footballs. Also, when they find such a hole they generally say it is in the neutral axis or excuse it on some such grounds. However, if you find a hole in the weld as large as a pea, the whole boiler must be condemned. Of course, caulking and peening each layer helps to remove this porosity but it is still there and will always be unless the weld is rolled or forged, the same as the parent metal.

This dissertation on porosity is being placed before you to show that if a weld could be made ductile, the welding being porous, what chance would it have of withstanding the strains equal to the parent metal which has been rolled or forged several times and which was a casting, originally? In advertisement and theoretical

arguments no holes and equal density can be obtained, but in actual practice you will find holes or lower density or both.

Fortunately, Nature or the Lord takes care of this and you cannot make a weld as ductile as rolled steel. Furthermore, its elastic limit is higher than that of the rolled steel so with an equal section which means a physical section divided by a percentage of porosity or density which is the measure when each pore is so fine you cannot see it, the deformation will take place in the parent metal. Visualize a test piece being pulled. If the weld is good it will begin to neck down outside the weld, the section then becoming increasingly smaller outside the weld and the welding is considered dandy although it has never been tested. This is the common way to test welds and even where all weld metal is tested and the testing shows it equal to rolled steel, the Lord has made the elastic limit higher in order to save us in our wild and foolish chase after ductility. The way to make the weld is to increase its section so that no strain will ever come on the weld. Just use it as a joint and forget about trying to equal the plates which may in themselves not be similar, one having been obtained from one mill to be joined to a plate of considerable difference. *Even if the weld were made better than the steel it joins, the joint would not be as good as the original metal because then all the bending would be focused at the edges and focusing strains at any one point is not good engineering.* Of course, enough ductility must be had to withstand the welding contracting strains, say, up to 20%, but beyond this it is foolish to go.

This brings up the question of *penetration*. If you give a welder a welding rod to test, he will bend it, hold it near his cheek and then finally weld with it. When finished, he will say it gives or doesn't give good penetration. What he means is that it melts at a certain rate which makes a larger, more shallow or deeper puddle, on the supposition that the weld is not as good as the parent metal.

Do you want penetration? Reflect. Of course, you don't. The least percentage of parent metal you replace with welding, the better off you are. For instance, suppose you wanted to build a tank which is one inch to one and one-quarter inch thick. The tank is rolled steel and the weld is cast. Would you be better off by putting penetration half of the inch thickness and having one inch of casting and half of rolled steel or would you be better off by leaving seven-eighths or fifteen-sixteenths of an inch and having only five-sixteenths or three-eighths of cast metal? Also in layer annealing the lesser the penetration the better and more sure the change to good grain structure.

Penetration in steel other than enough to get a good hold is not desirable. The above reason is only an entering wedge to start you thinking. Here's the real reason and the beauty and wonderfulness of arc welding —penetration in good welding is never deep enough to form a zone of weakness at the edge or in the weld. The deposit is wonderful steel, sometimes better than the original metal but with all the properties of a casting including porosity. And here again Nature won't let us penetrate far enough to do much harm and each layer wipes out the ill effect of the "penetration."

No mild steel weld can ever weigh as much as mild steel itself. Of course, with high price alloys greater density can be attained, but here again Nature or the Lord takes care of matters and the elastic limit is again raised beyond the reach of the unthinking and those who attempt to substitute opinion in place of research and reflection.

Welding as Applied to the Electrolux Refrigerator

By W. R. CAMPBELL *and* R. S. TAYLOR

†This paper will be presented during the Annual Meeting of the American Welding Society, April 27th to 29th, New York. Mr. W. R. Campell is Supt., Electrolux Machine Operation, and Dr. R. S. Taylor is Head of the Electrolux Research Dept., Servel, Inc.

AUTOMATIC household refrigerators are so well known and widely used today that they have long since become a necessity in many homes where they once were considered a luxury. Comparatively few of those utilizing modern domestic refrigerators realize the extent to which welding has been used in the manufacture of these important pieces of equipment. Fabrication of almost any of the high grade units today without welding would be extremely difficult. The Electrolux refrigerator more than any other depends on welding, and, in fact, it might be said that to build the Electrolux would be almost impossible were it not for gas welding and in particular oxyacetylene welding. The characteristics of Electrolux are such that there are serious obstacles in one's path if he attempts to apply any of the other known types of welding to the assembly of more than a few isolated parts.

Of the two general types of refrigerators in common use, Compression and Absorption, the Electrolux comes under the latter classification. The principal feature of the compression refrigerator is a mechanical compressor for compressing the refrigerant gas to a liquid which is permitted to expand, producing the refrigerating effect. The expanded gas is compressed again, repeating the cycle. Well-known examples of this type are found both in the small size or household refrigerator and in the industrial or ice and cold storage plant. With the absorption type the power-driven compressor is replaced by an absorbent and a source of heat. This is exemplified by Electrolux in the household field and numerous large installations in the industrial field, especially where low temperatures are required or where ample steam is available.

The Electrolux unit is compact and comparatively light in weight and has no moving parts to wear out or cause trouble. Energy is supplied by a small gas flame burning silently under automatic control. The small amount of gas and liquid contained in a hermetically sealed system of cylindrical vessels and tubes are so proportioned that when heat is applied at the generator, cold is produced in the evaporator, which is that portion of the unit located inside the food compartment of the refrigerator cabinet.

The most essential factor in the uninterrupted operation of the unit is permanent tightness in all joints, since the exactly proportioned refrigerant fluids are put in under a

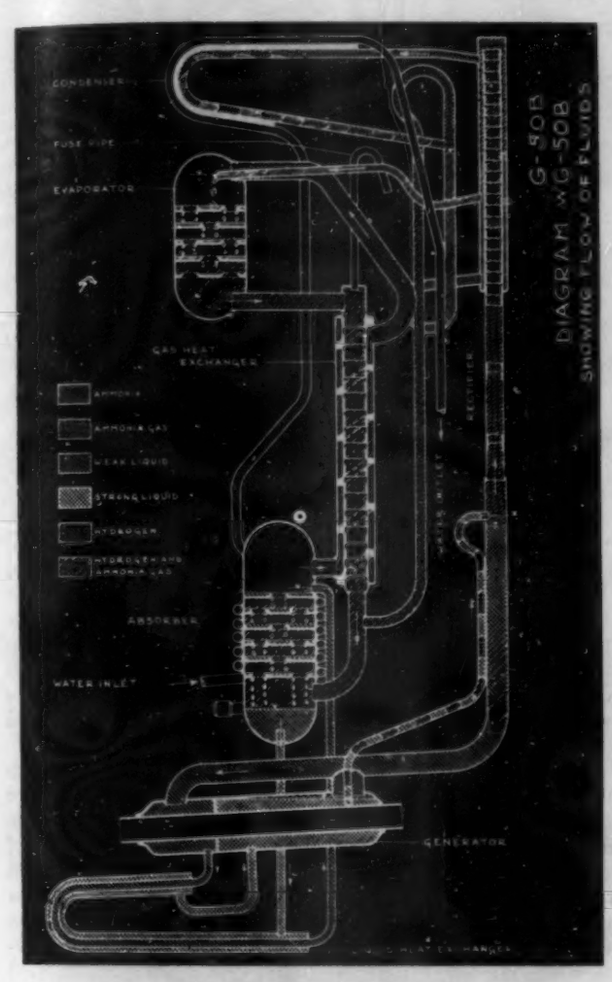


Fig. 1—Diagram of Unit

definite pressure, and the smallest leak would quickly lower the efficiency of the unit, soon stopping its action completely. This means that not only must the unit be welded up with the greatest of care but it must also be very carefully tested for leaks after welding and any leaks found must be repaired. In addition, since the unit contains hydrogen gas at over 200 lb. as well as ammonia and water, the system of testing must be such as to detect the most minute pinhole.

About 40% of the personnel in the entire Production Department of the Electrolux Division operate welding torches; consequently a description of the major manufacturing operations will show but few steps where welding is not concerned. As an introduction, however, a description of the unit will make quite understandable the reasons for fabrication by welding. Each unit consists essentially of seven parts known as the generator, liquid heat exchanger, absorber, condenser, rectifier, gas heat exchanger and evaporator.

A visual examination of the photograph of the unit will show that the device consists almost entirely of tubing and drawn shells of various diameters. The design of the unit is such that it will stand a pressure of over 3000 lb. without bursting. This excessive strength is not needed for the normal operation of the unit but is needed to make the high pressure leak test used in the factory safe.

There are 78 individual welds in each unit, making a total of approximately 150 in. of welding in metal ranging from No. 17 to No. 11 gage. Most of the parts are made from seamless steel tubing, and deep drawn steel shells.

To give some idea of its size, the largest unit made for domestic purposes fits into a space of 3.2 cu. ft., $5\frac{1}{2}$ in. in depth, 19 in. in width, and 52 in. over-all length. The flow sheet below summarizes the essential steps in the manufacture of the unit:

Raw materials
↓
Cut to length, clean if needed, bend, form drill or otherwise fabricate, clean, sandblast
↓
Welding
↓
Leak test and repair
↓
Pickle and galvanize
↓
Assemble into insulation box and charge unit
↓
Calorimetric test for capacity
↓
Final assembly of accessories to unit
↓
Installation in cabinet

In view of the fact that the unit must have long life, the utmost care must be exercised in the selection of raw materials used, and in its fabrication. The tubing and steel used falls within the following analysis:

Carbon	0.08–0.14	Silicon	0.05 Max.
Manganese	0.30–0.60	Copper	0.05 Max.
Phosphor	0.05 Max.		
Sulphur	0.05 Max.		

The analysis was set up to give a good welding steel soft enough to be fabricated into the intricate bends and coils required. The tubing is retort annealed to lessen scale formation to a maximum tensile strength of 51,000 lb./sq. in. The welding rod used falls within the AMERICAN WELDING SOCIETY'S specification No. G-1A as regards analysis, but the analysis alone is not sufficient to define a suitable rod. Freedom from inclusions, gas bubbles and scale is necessary also to get leak-proof welds. The percentage of leaks found on our test goes up immediately if a shipment of inferior rod is used.

The acetylene for welding is supplied through the aid of a low pressure non-automatic acetylene genera-

Fig. 2—Welding Gas Heat Exchanger on Conveyor

tor with a carbide capacity of 500 lb., and with an hourly rating of 3000 cu. ft. of acetylene. The generated gas is not turned directly into the supply line as is done when an automatic feed generator is used, but first conveyed to a large storage holder with a capacity of 2000 cu. ft. of acetylene. The feeding of the carbide to the generator can be started or stopped as desired. As the time required for charging is less than 20 minutes there is always ample time to replenish the supply in the storage holder to adequately supply the shop demand, assuring an uninterrupted supply at all times. This is an important feature where a conveyor system is used, because a hold-up would cause serious disruption in production. Oxygen is piped to the plant from a conventional 40-cylinder oxygen manifold which is so arranged that only 20 cylinders are feeding to the line at one time, the other 20 being held in readiness to be connected to the line immediately when the first 20 have been exhausted. The oxygen pressure is held to approximately 27 lb. per square inch, and the acetylene at about 14 in. water column pressure equivalent to 9 oz. gage pressure. Close attention was given to the proper design and erection of the new oxygen and acetylene piping systems so there would be no cause for interrupted service from this score. In making these installations of oxygen and acetylene supply lines valuable assistance was rendered by the engineers of the company supplying our oxygen.

After the cutting operations have been performed on the rough stock, consisting mostly of tubing, any forming necessary is done with the aid of special bending fixtures and machinery. The necessary holes are drilled or punched, and all burrs carefully removed. After the parts are thoroughly washed and steamed to remove all grease they are then put through a sandblast operation, using steel grit as the abrasive agent, and are then ready for the Welding Department.

When two pieces of tubing are welded together they are always formed or machined to fit closely so that a minimum of bridging over is required of the welder. It is found this minimizes leaks; also, where possible, the unit is designed to make it unnecessary to make one weld overlap the second.

Originally all welding was carried out using stationary tables, passing a part from one table to the next for subsequent operations. Heavy fixtures into which the welder cannot force a piece of incorrect dimensions are used, and all parts are tack welded together in the correct relationship in these, and taken out for finish welding. This finish welding was formerly done in stationary vises.

Fig. 3—Final Assembly Tack Welding in Fixture

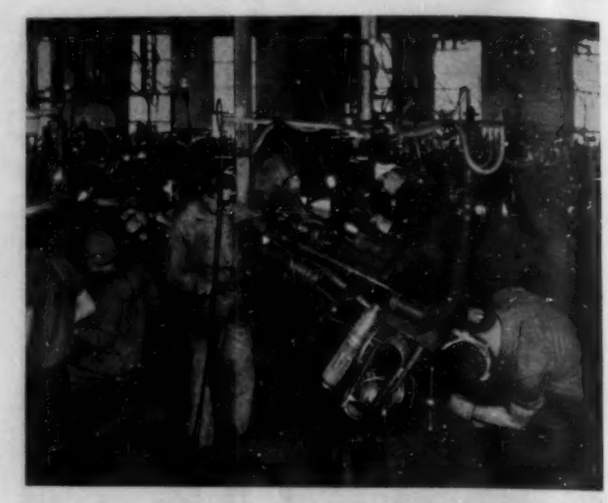


Fig. 4—Finish Welding of Unit on Conveyor

Frequent expansions of manufacturing facilities have been made since this refrigerator was first placed on the market, and toward the end of 1930 the output has increased to an extent that manufacturing by a continuous conveyor was justified. So far as was known welding had never been used for the fabrication of metal parts while moving on a conveyor.

Nevertheless, after consultation with various engineers it was decided the plan was quite feasible, so the entire manufacturing process was coordinated to the new scheme and a conveyor was placed in operation. It was, of course, necessary to continue production while the system was being installed. As fast as one section of the new production line was put into operation the old section which took care of the particular manufacturing operation was removed to make room for new equipment. All this was completed with but little disturbance to the manufacturing schedule, particularly since the change-over was made during the slack period in our yearly production cycle.

The flexibility of welding as a manufacturing tool has been clearly demonstrated in all previous expansions of the plant. It was merely necessary to train new welders, which was done in the school operated in conjunction with the Welding Department, provide new welding stations which are relatively inexpensive, and quickly install and provide other miscellaneous equipment such as jigs which were readily made in the plant.

Because of the constantly increasing expansion of the Welding Department it has been found very valuable to operate a welding school as an adjunct to the factory. Some experienced welders have been obtained locally, but as a rule it has been found more satisfactory to train men who have never done welding before. The capability of the apprentice welder when first put on a production job can very quickly be determined by the leak tests, in which all welds are examined with soapy water while the unit is under the 950 lb. per square inch of air pressure. This is very much greater than the operating pressure but it only amounts to about a third of the bursting strength of the weakest part of the system. This test is an excellent barometer of the capabilities of all operators and apprentices. The more experienced welder will have on an average about 3% of leaks reported back to him. The apprentice welder when first put on production work will quite naturally have a much larger percentage of leaks. Each operator is assigned to a particular weld, and it is a very easy matter to keep a complete

record of his work which is done by the leak testers who record the particular welds that are found leaking.

By this method the welders are all inclined to do their best work. Women quickly learn the technique of welding. Many have been trained for the lighter and more tedious jobs, and on this class of work they have worked out more satisfactorily than the male welders. In training welders bridging is taught rather than penetration. This is to prevent the welders from melting through small pipes and closing or partially closing these off, thus interfering with the operation of the unit. Welders are first taught on scrap plate material. They are then put on simple sub-assembly welds, and given more complicated welds as they become more adept. The best welders are used for repairing leaks found in welds previously made.

On some occasions when inexpensive fixtures of a temporary nature are desired a sample of the particular unit will be very carefully made up, and used as a model for building a fixture. A steel plate about $^{5}/_{8}$ in. thick and of the desired size, reinforced with channel iron to prevent warping while welding, is used for the base of the various locating vee blocks and saddles. Vee blocks

Fig. 5—Welding of Refrigerator Liners

and saddles are usually made from channel iron sawed to the desired length and shape. All of these parts are placed in position and welded to the base plate, making a very inexpensive fixture that can be used for several thousand jobs.

The Welding Department is laid out with the sub-assembly benches for tacking the parts together at right angles to the conveyor line. The conveyor is designed to travel along the line of production at a rate of 5 feet per minute for maximum production. At every four feet along the conveyor chain is a swivel vise for holding the work which is carried along on a small dolly supported by a fixed rail. Consequently, one unit every 48 seconds, or 75 units per hour, can be turned out when desired. The first part of the unit to be placed on the conveyor after assembly by tack welding is the gas heat exchanger. A sufficient number of operators are assigned to weld on this part so that each can finish welding his weld easily in the allotted time. Welding tips are specified for the weld to be made and low constant pressure acetylene assures the foreman that the welder uses the correct size flame. At a point where the welding has been completed on the gas heat exchanger are the tacking tables and fixtures for the evaporator shield plate assembly and the absorber assembly. These last-mentioned items are placed on the conveyor to ride to a point along the line where several first major sub-assembly tacking fixtures are located. They are then all removed from the conveyor for tack welding into a sub-assembly, and a tack welded sub-assembly put in its place, and the finish welding divided among the various operators and completed as before. At a point where these operations have been completed are located the sub-assembly lines of the condenser and rectifier assembly and the generator and liquid heat exchanger assembly. These lines run parallel to the conveyor and ride to a point where the conveyor makes a U-loop around the second or final assembly welding fixtures where they are taken off for tacking, and the operation repeated as before by placing back on the conveyor for a finish welding.

Following this, the complete unit is put through a straightening fixture to correct warpage due to welding, and four consecutive leak tests with a welder making the necessary repairs between each test. Three of these tests are with 900 lb. of air sealed in the unit for periods ranging from 5 to 15 minutes to make sure that if a leak is present it will show up as a bubble, or slight foam if the leak is small, in the soap solution poured over the welded joints.

After the brazing of the copper lines together and to the absorber, the assembly is removed to an overhead conveyor where it is put through a pickling and galvanizing process, following which the copper coil is soldered tightly to the absorber for better heat conductivity. Oxyacetylene blow pipes are used for all soldering operations. At this point the assembly has traveled 1021 feet on three conveyors, and the elapsed time is 3.4 hours.

Before the refrigerants are charged in, however, all parts of the unit from which it is desirable to prevent heat loss during operation are enclosed by a galvanized steel casing packed with mineral wool insulation material. The unit is then evacuated and charged with the required amounts of ammonia, water and hydrogen gas while moving on the conveyor. After this operation the unit leaves the conveyor and is placed on a stationary test rack where it is given a calorimetric test of several hours duration for refrigerating capacity. The test is carried out by introducing a definite amount of heat into the boiler and reading the temperature of the refrigerating compartment or evaporator when working under a known heat load. This temperature is compared with that obtained on a standard capacity or prototype unit operating under the same conditions. The utmost care and attention is given this test because by it is determined the ability of the unit to fulfill requirements. As a further check against the manufacturing calorimetric test a Control Laboratory is operated as an adjunct to the factory and a certain percentage of the units are picked at random from the test lines and given a very sensitive test in this department. The Control Laboratory also assists the Manufacturing and Inspection Departments in finding the defects causing a particular unit or batch of units to be rejected on the calorimetric or "cold" test. After the cold test the units are placed on another conveyor for final assembly where they are equipped with the aluminum chilliator casting, gas burner, gas thermostat, water control valve, etc.

After a general inspection the unit is placed on an overhead conveyor carrying it to the cabinet department where it is removed and installed in the cabinet of another conveyor.

Although the oxyacetylene welding of the Electrolux unit constitutes the major proportion of the welding on the final product, the discussion cannot be complete

without some mention of the welding of the cabinet and of the few points where it has been found advantageous to use electric welding.

The top and bottom of the refrigerator liner is welded to the sides clamped in stationary fixtures. The liner is made of Armco iron and girls do the welding. The edges are melted together with the torch and no filler rod is used except in rare cases. Then the filler material is part of the same material. Particular care must be exercised to keep the edges clean so that a weld free from pinholes is made because pinholes will frequently cause defective porcelaining.

As regards electric welding, there are two operations carried out on the unit which it might be interesting to mention. The insulation boxes are of galvanized iron, and are electrically spot welded together. The absorber and evaporator caps are welded on, using an automatic metallic arc welder.

In conclusion it can be said that the benefits which have resulted from the adoption of the conveyor system of production have been ample repayment for the expense of the change-over and the investment in new equipment. Lost motion in handling and stacking the various sub-assemblies and the completed units has been almost entirely eliminated, and the welding efficiency has been greatly increased. There has also been a decline in the percentage of leaks even though the welding is done while the work is moving. It has been found that the movement or the speed of the conveyor is not detrimental to quality work. However, the operation of the conveyor should be smooth and without any irregular motion. The most gratifying feature to the management, however, has been that the oxyacetylene welding process was so readily adapted to the conveyor system, and that production could thus be increased by 50% with but a 20% increase in the number of operators.

Engineering and Economic Study of Electric Arc Welding

By C. L. WADDELL

✦This paper will be presented at a Symposium on Ductility to be held during the Annual Meeting of the American Welding Society, April 28th in New York. Mr. Waddell is Welding Engineer for the Worthington Pump & Machinery Corp.

THE ART of electric arc welding has progressed to a point now where it is possible, by variation in chemical composition of the base metal type of electrodes and welding procedure, to produce welded vessels and structures for almost any conditions of service. Whether or not the completed vessel or structure meets the requirements depends upon the quality of design and fabrication.

The essentials of good weld design are: a complete knowledge of the conditions of service, an accurate analysis of the stresses, proper selection of materials and consideration of economy in fabrication. The essentials of good weld fabrication are: good materials of known chemical composition and physical characteristics, adherence to a definite proven weld procedure, skilled workmanship and competent supervision and inspection. Such failures as have occurred in welded construction are traceable to the neglect of consideration of one or more of these essentials.

Each of the problems incidental to the proper design and fabrication of welded steel vessels and structures has been made the subject of exhaustive research. It would be impossible in any one meeting to discuss them all fully. So it has been decided to direct the attention of this meeting to the physical characteristics of welds.

During 1931 the A. S. M. E. published a Code for Fusion Welding of Unfired Pressure Vessels which directed the attention of the industry to the physical characteristics of welds. In order to meet the requirements of this code for various classifications of vessels, most manufacturers have found it necessary to make an engineering and economic study of the problem. This paper outlines the results of such a study made by The Worthington Pump and Machinery Corporation during the past year to determine the limitations in physical characteristics of electric arc welds produced under shop conditions, using various types of bare and covered electrodes.

What is the most important physical characteristic of a weld? If this question had been asked a few years ago the answer would undoubtedly have been that it was tensile strength. Electrodes were sold on the basis of the tensile strength of the welds they would produce. If the question were asked now of a person who had just finished a study of the 1931 A. S. M. E. Code for the Fusion Welding of Unfired Pressure Vessels, his answer might be that it is ductility. As a matter of fact, the relative importance of the various physical characteristics of welds can only be determined by a knowledge of the conditions of service to which the welded vessel or structure will be subjected.

In order to obtain data for this study of physical characteristics of welds which would be comparable for the various types of electrodes, all test plates were made in accordance with standards set up by the insurance companies and later adopted by the A. S. M. E. in the

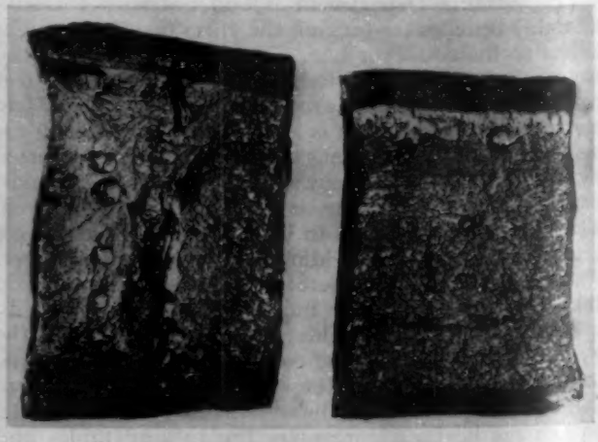


Fig. 1—Nick-Break Test Coupons

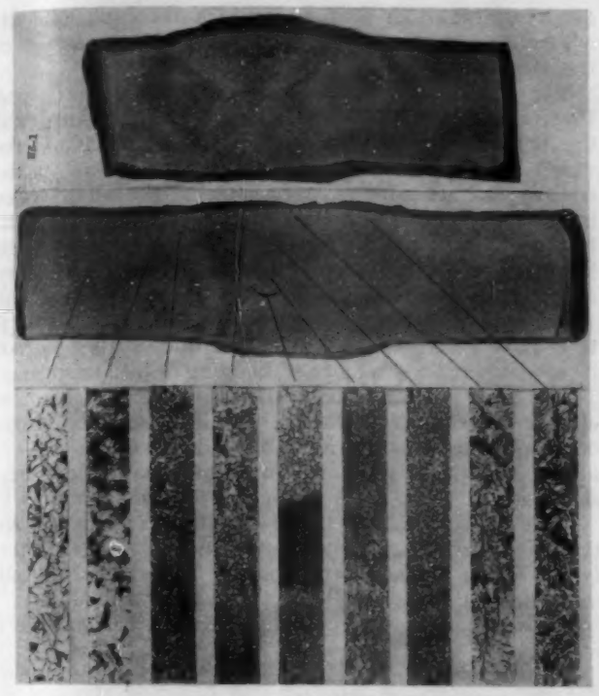


Fig. 2—Etch Samples and Micro-Photographs of Grain Structure at 100 Magnifications

Unfired Pressure Vessel Code. Two low carbon steel plates 9 in. x 18 in. were butt-welded along the 18 in. side after both plates had been double beveled to form a welding kerf. No more than two beads were applied to one side of the kerf in succession. The same operator welded all test plates except those welded on operators' qualification tests so as to eliminate the element of skill in the consideration of the test results. A time study was made during the welding of each test plate which furnished data for the cost analysis. Two tension, two free-bend and two nick-break test coupons and one etching sample were obtained from each test plate. The tension and free-bend tests were conducted on a calibrated Olsen testing machine and the nick-break coupons were broken under a steam hammer. The etching samples were polished and etched with a 10% solution of ammonium persulphate to bring out the grain structure and any defects that there might be in the welds.

The test which gives the most information as to the physical characteristics of a weld is the nick-break test. The number and strength of blows necessary to fracture and the amount of bending of the test coupon before fracture give an indication of the ductility of the weld. Coupons welded with bare electrodes usually broke on the first sharp blow, showing lack of ductility, while several blows were struck and considerable bending took place before the covered electrode coupons were fractured. Examination of the cross section of the fracture gives an indication of tensile strength and ductility of the weld. Defects such as gas pockets, failure of fusion and slag inclusions decrease ductility and tensile strength. Coarse grain structure without defects indicates low ductility but does not materially affect tensile strength. Refined grain structure indicates high ductility and tensile strength. When the nick-break test showed a defective weld or coarse grain structure, it was not considered necessary to run the free bend and tension tests. Figure 1 shows two nick-break test coupons made with different types of covered electrodes. The one shows coarse grain structure, failure of fusion and gas pockets and broke with a single sharp blow. The other had refined grain structure and no defects except two minute gas pockets and met all the requirements of a good commercial Class 2 weld under the Unfired Pressure Vessel Code.

Next to the nick-break test as a source of information as to physical characteristics of welds, the etch sample was found most valuable. The information obtained from a study of the etch sample is much the same as obtained on the nick-break tests. The grain structure is more clearly defined and it is possible by microphotographs to study the defects and determine the cause. Figure 2 shows two etch samples and micro-photographs at 100 diameters at the points indicated in the defective weld. The failure of fusion was due to oil from a chipping tool used to chip out the reverse kerf and to slag inclusion in the bottom of a kerf which had been chipped too narrow. The top sample shows a cross section of a good commercial weld which met every requirement for Class 2 welding under the Unfired Pressure Vessel Code. The refinement of grain structure by heat in applying successive beads is clearly shown where weld procedure was followed.

The tension tests showed that in all cases the tensile strength of both bare and covered electrode welds was greater than the nominal tensile strength of the plate and in many cases greater than the actual tensile strength of the plate. Where failure occurred in the weld the cause was traceable to defects such as gas pockets or failure of fusion. The test results are shown in Tables 1 and 2.

The physical characteristic of welds which has attracted the most attention during the last two years and especially since the adoption of the 1931 Unfired Pressure Vessel Code is ductility. Table 1 shows the ductility test data on four leading types of bare electrodes. Table 2 shows the ductility test data on five leading types of covered electrodes. The letters indicate electrode type and (*) indicates changes in the chemical composition of covering or base metal in the electrodes by their manufacturers. The test results show that the use of bare electrodes is limited to Class 3 vessels under the Unfired Pressure Vessel Code and that all four types of bare electrodes meet the ductility requirements for this class. All five types of covered electrodes meet the requirements for Class 2 vessels under the code. Figure 3 shows two free-bend test coupons cut from the same test plate. One showed 64% elongation in ½ in. of weld metal and the other only 44% before failure occurred on the corner due to the presence of minute gas pockets.

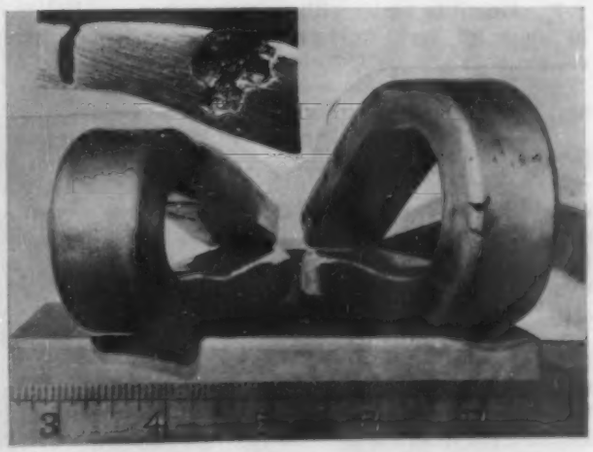


Fig. 3—Free-Bend Test Coupons

Above the two is a magnified section through the gas pockets.

During the period of tests the following observations have been made regarding ductility in welds:

1. Ductility decreases with increased carbon content of base metal and electrodes.
2. Ductility tends to decrease with increasing tensile strength in welds free from defects. (Table 1 shows this clearly. In Table 2 the same relationship exists but is not so evident due to defects in the welds.)

Table 1

Type Electrode	Plate Thickness	Date Tested	Average Tensile Strength Lb./Sq. In.	Average % Elongation in 1/2 In. of Weld Metal
A	3/4 in.	12-8-31	61875	12.00
B	3/4 in.	4-2-31	60150	15.15
C	1/2 in.	6-22-31	55125	16.00
D	1/2 in.	4-21-31	58100	19.37

Table 2

A-1	1/2 in.	2-6-31	54760	22.00
A-2	3/4 in.	2-6-31	57170	22.20
A-3	1 in.	2-6-31	56750	20.00
A-4	1 1/4 in.	2-6-31	57050	20.80
A-5*	1/2 in.	7-8-31	59300	40.63
A-6**	3/4 in.	1-7-32	61650	54.00
B-1	1/2 in.	4-1-31	60860	28.65
B-2	1/2 in.	4-21-31	56260	33.65
B-3	1/2 in.	6-1-31	58650	30.00
B-4	1/2 in.	6-1-31	60350	32.00
B-5	1/2 in.	6-1-31	58750	24.00
B-6	1/2 in.	6-1-31	60350	30.00
B-7*	1 1/4 in.	6-23-31	48950	20.00
C-1	3/4 in.	6-23-31	56425	20.20
C-2	1 1/4 in.	7-6-31	57925	28.00
C-3	1/2 in.	7-6-31	57950	20.00
D-1	3/4 in.	12-18-31	62520	38.67
D-2	3/4 in.	1-7-32	60950	35.00
E-1	3/4 in.	1-7-32	62100	26.00

3. Application of beads in rapid succession and use of high welding current gives refinement of grain structure and increased ductility.
4. Hot peening of weld relieves residual stress and strain and increases ductility.
5. Ductility increases with density. High density obtained by refined grain structure and absence of defects.
6. Defects on the surface or corners cause free bend test coupons to show low ductility on test. (See Figure 2.)
7. Ductility varies with weld procedure. (Variations in shape of kerf, welding currents, method of stress relieving, hot or cold working.)
8. Ductility varies with skill of operator. (Length and steadiness of arc, adherence to weld procedure.)

That ductility is an important physical characteristic in welds cannot be denied. The greatest strides in the welding industry have been made since changes in electrodes and procedure have made it possible to produce ductile welds. But we must not let this observation lead us to believe that ductility is a panacea for all the evils of welded construction. It is not. Neither is strict adherence to the requirements of the Unfired Pressure Vessel Code. A vessel or structure may be fabricated of the best materials obtainable and the welds may be as near perfect as it is possible to make them and yet the structure may fail in service. Why? Because the design is such that no material or weld could stand up under the stress concentrations. The engineering is at fault either because of a lack of complete knowledge of the conditions of service or improper analysis of the stresses.

The various classifications of welds in the Unfired Pressure Vessel Code are based upon plate thickness and the temperature and pressure of the gas or liquid the vessel will contain in service. A vessel meeting all the code requirements for a Class 3 vessel might fail in service because it was subjected to impact, bending or fatigue loading. The code could not be blamed for the failure because it was only formulated as a guide for the industry and not to cover all the special conditions of service. Here again the engineering is at fault. The physical tests have shown that welds of low ductility should not be used where there is impact, bending or fatigue loading.

The need for research in the problems presented by electric arc welding is evident. To know the limitations of the physical characteristics of welds of various types is important but it is equally important that proper consideration be given to the design of welded structures.

Time study data was taken on all tests using various types of electrodes but cost analysis only made on the types which satisfactorily passed the physical and metallurgical tests. The data taken were as follows:

1. Number of electrodes used for 18 in. long butt weld.
2. Burning time for 12 in. of a 14-in. electrode at best welding current and voltage.
3. Total time burning electrodes.
4. Total cleaning time.
5. Overall welding time.
6. Cost of electrodes.

On bare electrode welding Type D electrodes effected a saving of 7% per man hour over all other types. On covered electrode welding Type A-6 electrodes effected a saving of 10% per man over all other types. Since both of these electrodes showed most satisfactory results on the physical tests they were adopted as standard until such time as tests will show other electrodes to be superior.

The most startling discovery of the entire study was the slight difference in the cost of welding with bare and covered electrodes. Proper fixtures for handling to permit downhand welding necessary with covered electrodes may make it possible to equalize these costs. Under these circumstances it would be possible, where ductility is required, to obtain it at no extra cost to manufacturer or consumer.

The past year has seen greater progress in the art of electric arc welding than any other in its history. Electrodes have been improved, procedure revised, standards adopted, costs reduced and the field of application of welding materially increased. This study covering a period of such progress has been particularly beneficial to the manufacturer. First-hand knowledge has been obtained through tests, operators have improved their skill and been qualified for Code welding and economies have been effected through proper design and selection of materials and decreased labor and overhead costs. Since the art is still progressing rapidly, the continuation of study and research by manufacturers is practically a necessity.

Annual Meeting Program

April 27th to 29th

Operates on Daylight Saving Time

Weld Ductility Requirements for Welded Pressure Piping

By T. W. Greene

†This paper will be presented at a Symposium on Ductility to be held during the Annual Meeting of the American Welding Society, April 28th, New York. Mr. T. W. Greene is Development Welding Engineer, The Linde Air Products Co.

Fig. 2—"Slack Wallops" Impose Temporary High Stresses in Welds

DUCTILITY and its value relative to other properties of materials are important considerations in the evaluation of serviceability of all materials. It is intended, in this paper, to limit the consideration of ductility primarily to the field of welded piping, attempting to indicate the amount that appears to be necessary to meet satisfactorily engineering requirements and to discuss its importance relative to other properties, particularly strength and quality, the latter being associated with those properties essential to a good weld, as density, homogeneity and freedom from defects causing stress concentration.

Ductility in engineering work is conceived as the ability or property of the material to stretch plastically under stress without failing. Its numerical evaluation is based on purely empirical and arbitrarily established methods of measurement. Usually in the testing of materials, it is numerically presented as the elongation before failure, expressed in percentage, when the material is subjected to a unit directional tensile stress. It may be measured over 2-in. gage length, which gives a maximum value as it includes the phenomenon of necking down, or in 8 in., or some other longer arbitrary length. By reason of such method of evaluation, a certain material is considered to be very ductile if it necks down markedly, which gives it a high numerical rating, although by no means does it necessarily follow that the same material will have a high serviceability rating for many engineering uses.

The stress-strain relationship may be considered as composed of three principal parts or phases, each representing a different phenomenon. The first phase is the elastic stretch or strain, proportionately related to the load or stress. This elongation, although it may be only 0.1 per cent, and rarely exceeds 0.5 per cent, is probably the most important because it is in this range where most load-carrying structures work. Its numerical value is determined by the constant relationship of stress to strain, known as the modulus of elasticity, and by the proportional or elastic limit of the material. The second phase is the plastic stretching occurring after the elastic limit is exceeded up until the maximum load is reached. This phase, representing from 50 per cent to 95.5 per cent of the total elongation, is important for slight cold working and deforming, or for providing against: unforeseen overstressing, resulting from incorrect designing, producing stress concentration as at fillets, notches, openings, etc.; faulty workmanship; imperfect material; or unforeseen service stresses. The third phase is the stretching, or rather, flowing, of the material under the maximum or even reduced load usually attended with the phenomenon of necking down. This phase is the least important, although it may represent 50 per cent of the total stretching.

As an example of the varying magnitude of the three phases of stress-strain relationship, a comparison may be presented between the ductility of low and high carbon pipe. Figure 1 shows the failure of low carbon, lap welded, pipe having a yield point of 28,000–35,000 lb. per sq. in. and an ultimate of about 50,000 lb. per sq. in. The elastic phase of such a material is small as the yield point is low, but the second and particularly the third phases are very high. The total stretch in 48 in. across

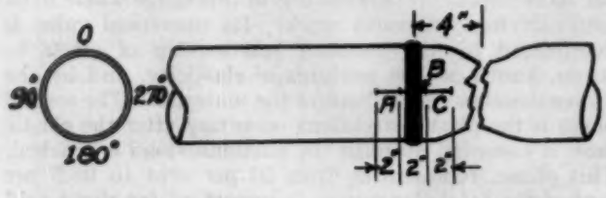
Fig. 1—Tensile Test of Welded 8" Low Carbon Pipe Showing Plastic and Necking Down Phases of Ductility

the point of failure is about 24 per cent. This would be rated as quite ductile material. A similar test on 0.30–0.40 C pipe, having an elastic limit of 45,000–60,000 lb. per sq. in. and an ultimate strength about 75,000–80,000 lb. per sq. in., showed 18 per cent elongation in 48 in. For this material the elastic phase is about twice as high as for the low carbon pipe but the plastic phase is somewhat less. The third phase in connection with necking is relatively insignificant. The technical worth of this high carbon pipe or its ability to carry load and pressure safely is very much higher than for the low carbon pipe, although by our method of measurement its ductility is seen to be only three-quarters as much. For pipe that has to be cold or hot bent, the serviceability rating of the low carbon pipe would unquestionably be greater. Thus engineering judgment is necessary in deciding the serviceability of materials from our ductility measurements.

Fig. 3—Cold Bend of Pipe at Weld. Severe Conditions Establishing Minimum Ductility for Weld

Table 1—Elongation in Weld and Pipe—Tensile Test Full Size Pipe Joints

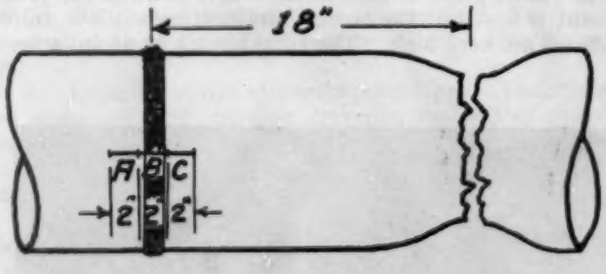
Specimen No. 6509—Butt Weld—8″ St.
Y. P.—36,700 lb. per sq. in.
Ult.—54,200 lb. per sq. in.



Elongation measured in 2″ at A, B and C

Position on Circumference	Per Cent Elongation in 2″ at A Adjacent	B Across Weld	C Adjacent
0	3.9	9.4	22.6
90°	12.5	9.4	20.3
180°	8.6	8.6	19.6
270°	9.3	8.6	11.7
Avg.	8.6%	9.0%	18.5%

Specimen No. 6517—Butt Weld—16″ O. D.
Y. P.—32,900 lb. per sq. in.
Ult.—54,400 lb. per sq. in.



Position on Circumference	Per Cent Elongation in 2″ at A Adjacent	B Across Weld	C Adjacent
0	14.9	12.5	27.3
90°	21.8	12.5	14.7
180°	23.4	10.9	12.5
270°	21.8	11.7	13.3
Avg.	20.5%	12.0%	17.0%

A certain amount of weld ductility is of paramount importance in welded piping. Probably the greatest need for weld ductility is exemplified by the requirements imposed in the construction of overland pipe lines. Figures 2 and 3 illustrate rather severe conditions, showing the necessity of ductility as well as quality and strength. The first illustration, bending pipe for "slack-wallops," which are temporary, pertains more to the elastic rather than plastic phase. The stresses are high, and for large diameter pipe may range from 40,000 to 50,000 lb. per sq. in. or possibly a little greater if high elastic limit material is used and the "wallops" are crowded. Moreover, the pipe must work under expansion and contraction until buried and is often further deformed when lifted by a tractor during the construction operations. Thus the metal is stressed from 50 to 75 per cent of its ultimate strength but, of course, the metal is deformed to only a small fraction of its total ability to stretch.

Cold bending of pipe, illustrated in Fig. 3, requires plastic stretching or ductility. This is an excellent weld test. Let us determine the ductility necessary to meet such a severe condition. Figure 4 shows a pipe bent to a radius of five diameters. Ordinarily in the shop this is done hot. Done cold in the field, even for a small distance to give change of direction less than 90°, it represents about as severe a condition as any weld would be required to withstand. Assuming the neutral axis remains the neutral stress plane in bending, the stretching of the outer fiber for 2-in. pipe would be about 12 per cent and for 10-in. pipe about 11 per cent. Actually, the stretching is decidedly less because of the shift of the neutral stress plane, incipient buckling on the compression face and the change to a slightly elliptical shape. Also the fact that the weld has a higher yield point and a greater cross-sectional area, which reduce the stress intensity, causes a greater proportional stretching to occur in the base metal than in the weld. Ten to twelve per cent, therefore, may logically be taken as a minimum requirement of weld ductility, for assuredly any weld, having the other requisite properties of strength and quality to withstand such treatment, should give entirely satisfactory service. Values shown in Table 1 corroborate this.

Having attempted to establish a minimum value, our next step is to analyze the value to be placed on higher ductility and what relative importance ductility bears to other properties.

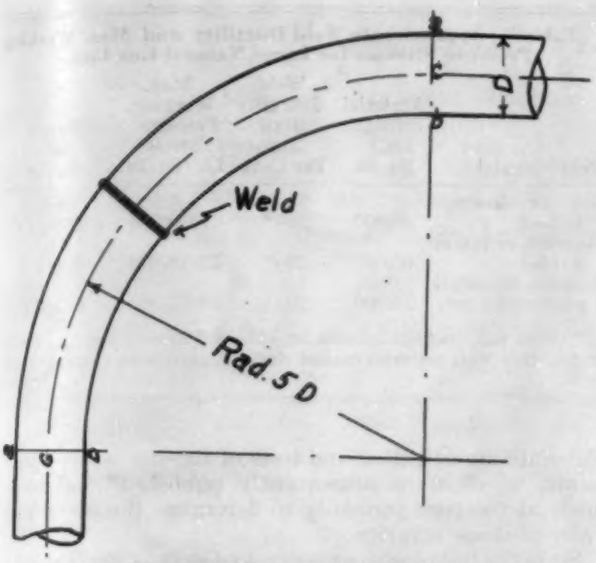


Fig. 4—Pipe Bend Containing Weld

Dr. A. B. Kinzel, in a paper before the A. S. M. E. entitled "Evaluation of Technical Worth of Steel from Physical Test Data," mathematically expresses the technical worth of materials and welds based on their various properties. The engineer, from his experience, stipulates minimum values for the properties on which he is basing his design. In this way he insures the sufficiency of the factor of safety. This paper shows how the various properties of steel may be used to help determine the most logical factor of safety. It is based on the quantitative evaluation of the technical worth of the material for a particular service, the technical worth being the ability of the material to withstand service stresses. Depending upon the application, this may be either the maximum allowable fiber stress, if it is a load carrying structure, or this may be the ability of the material to withstand stresses which result in plastic deformation without fracturing, as for deep stampings.

In the use of steel for load carrying structures, present standards require that the steel must have a certain strength (ultimate strength); it must have a certain ability to resist deformation (yield point); it must have a certain ability to deform uniformly (elongation); and locally (reduction of area) without fracturing. For some applications it must have certain other properties. As an example, in some cases, it must have resistance against repetition of stress (fatigue) and for high temperature piping it must not show too large a reduction of strength at high temperatures and must be able to withstand long-time stress application (creep).

The properties in question are factors, although not necessarily factors of equal importance, nor are all involved in any application. As each factor involved must be proportionally weighted, the most convenient method of weighting a factor is to give it an exponent whose value may be varied for any particular case. The relative worth of different materials or of the same material, as a weld, having different properties, may be expressed by the following general formula:

$$\frac{w}{W} = \left(\frac{y}{Y}\right)^{s}\left(\frac{u}{U}\right)^{m}\left(\frac{b}{B}\right)^{n}\left(\frac{h}{H}\right)^{x}\left(\frac{c}{C}\right)^{z} \ldots\ldots \text{etc.}$$

where w = technical worth or design stress of one material having certain properties; W = technical worth of another or same material possessing different properties; y = yield point; u = ultimate strength; b = ductility in bending; h = hardness; c = creep, etc.

In the present discussion we are primarily concerned with only two factors: strength and ductility. It is interesting to see how these factors are related in the technical worth of a weld. Let us take the one outstanding example, the A. S. M. E. Unfired Pressure Vessel Code, which is becoming an important precedent. In this Code, varying weld strengths and ductilities are set up for different classes of vessels to which different design working stress values are assigned. The above general formula may be written for this case,

$$\frac{w}{W} = \left(\frac{u}{U}\right)^{1}\left(\frac{b}{B}\right)^{n}$$

or

$$\frac{w}{8000} = \frac{u}{47{,}500}\sqrt[n]{\frac{b}{20}}$$

$$w = \frac{u}{5.95}\sqrt[n]{\frac{b}{20}}$$

where w = worth or design working stress of one classification; W = design working stress of another classification. The numerical values of U and B are

Table 2—Evaluation of Technical Worth or Design Stress Based on Weld Strength and Weld Ductility

As Required by Unfired Pressure Vessel Code

Class of Vessel and Plate Material Min. Spec. Lb./Sq. In.		Minimum Weld Strength Requirements		Min. Ductility Bend Test Elongation	Allowable Design		Technical Worth by Formula		
					Joint Efficiency	Working Stress	$S=\frac{u}{5.95}\sqrt[n]{\frac{b}{20}}$	$S=\frac{u}{5.95}\sqrt[5]{\frac{b}{20}}$	$S=\frac{u}{5.95}\sqrt[4]{\frac{b}{20}}$
		%	Lb./Sq. In.	%	%	Lb./Sq. In.			
Class 1	50,000*	100	50,000	30	90	9000	9600	9100	9000
	55,000*		55,000			9900	10,500	10,000	9900
	62,000**		62,000			11,100	11,900	11,300	11,100
Class 2	50,000	95	47,500	20	80	8000	8000	8000	8000
	55,000		52,300			8800	8800	8800	8800
	62,000		58,800			9900	9900	9900	9900
Class 3	50,000	85	42,500	10	†	8000	5700	6200	6400
	55,000		46,800			8000	6250	6850	7000
	62,000		52,700			8000	7000	7700	7900

* Specification S-1 for Steel Boiler Plate, Section II of the Code (1930 Edition).

** Specification S-18 for Welded and Seamless Steel Pipe (1930 Edition).

†Maximum unit joint working stress ($S \times E$) is 8000 lb. per sq. in. for double welded butt joints irrespective of strength of base material.

for Class 2 vessels taken arbitrarily for comparison (values for Class 1 could just as well be taken).

Table 1 shows the minimum weld strengths, ductility requirements and allowable design stress of the Code for different classes of vessels. In the last three columns are presented the mathematical relationship of varying properties by the above formula with ductility proportioned to the third root, the fifth root and the sixth root. It will be seen that the technical worth or the permissible design values for welds in the three classes of vessels vary closely as the sixth root of the ductility requirements. This means, expressed in percentages, an increase of 50 per cent in ductility (bend test) would, under the standards of this Code, allow an increase of only 7 per cent in design working stress. Doubling ductility, 100 per cent, would permit an increase of only about 12 per cent.

It should be pointed out that the varying requirements in the Code relating to ductility were probably established not so much to permit different design stresses as to assure quality of the weld. This is attested to by the fact that where a higher technical worth or design stress is given the weld, Class 1, other requirements are set up to assure quality, as X-ray of every inch of the welded seam, specific gravity test (a purely quality test) and stress relieving to leave the weld in the most favorable state. Thus, the relative importance of ductility is even less than shown by the above mathematical analysis and quality is by far the more important weighted factor.

It may be of interest to examine the relative importance of ductility to strength and quality as based upon present practices in the pressure piping field. In power piping the numerical evaluation of the importance of ductility is obscure, for in this field design pressure stresses are usually very low and factor of safety against internal pressure extremely high. For high temperature service, since the ductility of steel and welds increases, the most important factors unquestionably are reduction of strength with temperature, and creep.

As mentioned before, there is one field of piping in which engineering practices and welding have pioneered to a greater extent than any other, for overland distribution of oil and gas. Here, for economic reasons, the tendency has been for increasingly higher pressures and higher strength materials. Table 3 shows approximately the weld qualities and working stresses for large transmission lines. These are not to be considered exact, but they do show the tendency of practices. It will be seen that with the higher pressures and higher strength materials the ductility of welds, as is the general nature of all steels, decreases. Higher stresses and lower factors of safety are used with lower values of ductility which is necessitated by the very nature of materials and conditions. It should be remembered, however, that when the lower factors of safety are used, closer inspection is maintained and quality of weld is insisted upon and secured in the field. Thus, again, quality is unquestionably as important as ductility.

Although weld ductility far exceeding the minimum values previously suggested for piping services can be secured by either gas or electric welding processes, the value of such increased ductility has been indicated to be relatively unimportant as the basis of the technical worth of welds, as established in the A. S. M. E. Unfired Pressure Vessel Code. Further substantiating this are the results of a very comprehensive series of tests made some years ago which quantitatively illustrate the relative values of these factors. These tests were made on full-size welded joints in 16 in. O. D. lap welded steel pipe of $^5/_{16}$-in. wall. These tests were made subsequent to an elaborate investigation and tests of full-size welded pipe joints, which were subsequently published* and were made at the time primarily to determine the effect and value of stress relieving.

Table 3—Approximate Weld Ductility and Max. Working Pressure Stresses for Large Natural Gas Lines

Pipe Material	Material Strength Lb./ Sq. In.	Weld Ductility Bend Test Per Cent	Max. Working Pressure Stress Lb./Sq. In.	Factor of Safety
Lap or hammer welded	50,000	30–*	7–10,000	7–5
Seamless or fusion welded	65,000	25–*	12–18,000	5.4–3.6
Seamless or special processed pipe	75,000	20–	18–25,000	4.2–3.0

* Often full ductility cannot be obtained due to the fact bend test in thin wall material cannot develop maximum elongation of weld.

Six of the full pipe size specimens, Group A (see Table 4) were normalized by putting them in a large furnace and heating to slightly above 1700° F. or above their critical temperature. This heat treatment which, of course, is very much higher than required to stress relieve (1000–1200° F.) refines the grain and markedly increases the ductility of the welds. Another group of welded full-size joints, B, Table 4, were tested as made without heat treatment but in this group a thin $^1/_{16}$-in. liner was used to back up the weld to guarantee that the weld was fused completely to the bottom for every inch of the circumference. One-half of the joints in each group had the reinforcement machined off before test, the other half of the specimens were tested with the usual reinforcement.

From results of these tests, Table 4, it will be seen that welds which were not heat treated, but for which means were taken to assure maximum quality, invariably outpulled the pipe even though the reinforcement was removed. Moreover, they were repeatedly loaded to four-fifths the ultimate strength before final test to destruction. In the normalized group some failures occurred in the weld, initiated through some minor defect. The ductility of the normalized group was at least twice that of the untreated welds as manifested by the way the welds necked down and in some cases progressively failed through flow and stretch of the metal, similar to failure in extremely ductile pipe metal. These test results are convincing in showing that quality of weld is far more important than ductility.

Before concluding, it is desirable to point out one limitation of our method of measuring weld ductility as applied to the piping field. The free bend test is receiving general acceptance as the test for weld ductility.

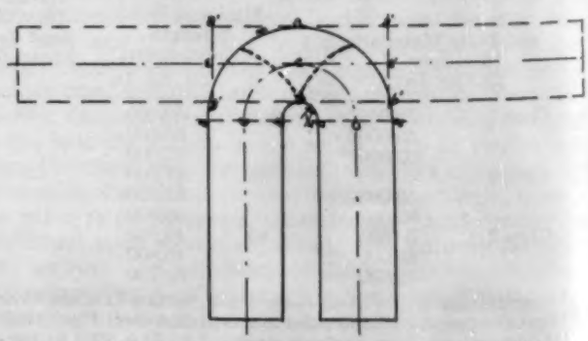


Fig. 5—Free Bend Coupon

* American Gas Association's Pipe Joints Committee Report 1928.

Table 4—Tensile Test Full Size Welded Pipe Joints

16 In. O. D. L. W. Steel Pipe—Wall 5/16 In.

Specimen No. Plain End Pipe	Specimen No. Joint Specimen	Ultimate Strength Plain End Pipe, Lb./Sq. In.	Strength of Welded Joint Specimens: Yield Point Lb./Sq. In.	Strength of Welded Joint Specimens: Ultimate Strength Lb./Sq. In.	Joint** Efficiency	Failure of Welded Joint Specimens
Group A. Welded Joint Spec. Normalized (Heated Above 1700° F.)						
Welds Reinforced						
9	10–11*	56,600	36,300	53,100	100%	Outside joint in grip
7	18–19*	56,000	34,500	55,000	100%	Outside joint in grip
21	22–23*	58,700	35,600	50,000	85%	1/2 through weld and 1/2 pipe. Unfused at bottom for 2" one spot. Three other spots 1/4" long unfused
	Average	57,100		52,700	95%	
Welds Ground Flush with Pipe						
49	50–51	53,700	33,000	46,600	87%	In weld and pipe. Fracture was observed to start and progress from a spot that was unfused for 1" or so along the bevel
53	54–55*	54,100	33,300	50,500†	93%	In weld and pipe. Pipe and weld necked down and progressively failed as characteristic of failure in pipe. Weld excellent
57	58–59*	51,800	33,000	46,000	89%	Through weld. Four spots 1/8" to 2" long showed half of bevel unfused. Structure of all annealed welds very fine crystalline
	Average	53,200		47,700	90%	
Group B. Joints Welded with Thin Backing-up Liner to Assure Quality						
Welds Reinforced						
37	38–39*	50,800	30,300	50,000	100%	Outside joint 4 ft.
41	42–43*	37,900	32,800	56,000	100%	Outside joint in grip
	Average	44,400		53,000	100%	
Welds Ground Flush with Pipe						
25	26–27*	50,200	29,900	48,600	100%	Outside joint in grip
29	30–31*	53,500	31,400	51,200	100%	Outside joint 3 ft.
33	34–35*	54,000	33,000	54,500	100%	Outside joint 3 ft.
	Average	52,600		51,400	100%	

* Joint specimens were surged or subjected to repeated loading, i. e., were stressed to about 40,000 lb. per sq. in. three times and released and then tested to destruction.

** Joint efficiency taken as 100% if specimen failed outside of weld. Efficiency for specimens failing in weld based on material test, plain end pipe specimen.

† Pipe first broke in grip at 45,700 lb. per sq. in. Joint was then retested, failing at 50,500 lb. per sq. in.

This is due to the fact that tensile test does not give a true total stretch of the weld metal (see Table 1) because of the higher yield point of the weld as compared to the base metal. Tensile test, likewise, of pure deposited weld metal is not adaptable because it is both expensive and misleading in that it does not record the influence of the base metal on the weld metal. The bend test may either be made by deforming the specimen containing the weld with a loading pin when supported as a beam, or the specimen may be bent by compressing between the jaws of a vise or heads of a press after initially crimping the ends of the specimen to start bending.

Figure 5 shows a "hair pin" bend made by this method. The thickness of the material decidedly affects the results. Assuming that the plane c'-c-c' through the center of gravity remains the neutral stress plane in bending, the outer fiber a'-a-a' must elongate 80 per cent if the specimen is 2 in. thick; 66 per cent if 1 in. thick. For 1/4-in. plate, the elongation is only 33 per cent. The shifting of the neutral plane, of course, somewhat modifies these values. The writer, however, in observing numerous field tests, has not been able to obtain in 1/4-in. to 5/16-in. pipe material elongation greater than 25 per cent to 35 per cent, even though the specimen is bent until in contact. There is, thus, a limitation to the maximum value of ductility by our test method for the vast range of pipe sizes. Yet such a test is severer than is required for any material by the A. S. T. M. standard method of pin bend test and more than ample to assure satisfactory service in any welded piping application.

In conclusion, the following may be summarized with regard to the importance of ductility as compared to other weld properties for piping services:

1. A ductility of 10 per cent to 12 per cent seems sufficient to meet all service requirements of pressure piping. While ductility far exceeding this range can be readily secured in fusion welds, there appear to be no requirements in piping services which would justify the establishment of any higher ductility specifications.

2. Strength in the weld metal equivalent to the base material and quality or freedom from imperfections are of far more importance than relatively high ductility.

Written Discussion on Ductility Particularly Invited.

Send These to Editor as Soon as Possible.

Spot Welding of Stainless Steel as Applied to Aircraft

By CARL DeGANAHL

†This paper will be presented during the Annual Meeting of the American Welding Society, April 27th to 29th, New York, by Mr. Carl DeGanahl, President, Fleetwings, Inc.

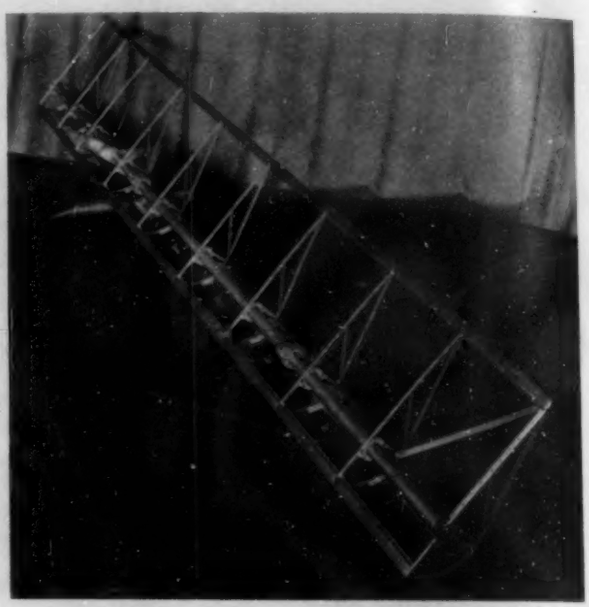


Fig. 1—Airplane Wing Aileron of Spot Welded Stainless Steel

A LITTLE more than two years ago an investigation of electric spot welding as particularly applied to aircraft was started by the author's firm. The advantages of stainless steel were soon obvious and the work quickly concentrated in this direction.

The particular stainless steel chosen is what is known as the 18–8 alloy. It contains about 18% chromium and 8% of nickel and very low carbon. The better known trade names of this alloy are Allegheny Metal made by the Allegheny Steel Company, KA2 made by the Crucible Steel Company, Carpenter 4 made by the Carpenter Steel Company and there are various other producers of the same alloy. This alloy was chosen because of its peculiar suitability to spot welding, its good forming qualities, even when hard rolled and the elimination of any necessity for subsequent heat treatment. It is an austenitic alloy having physical properties strangely similar to copper. In its full annealed condition it has an ultimate tensile of around 90,000 lb. per square inch with a very low yield point around 35,000 lb. per square inch. Its elongation, however, is exceptionally high, being about 60%. It is due to this high elongation that it is such an easy metal to form and work.

These low physicals, however, can be radically changed by cold working. Strip, cold rolled as high as 220,000 lb. per square inch ultimate tensile, has been used. However, the elongation is very low, generally about 2% or less, and further forming and working is impractical. It is preferable to use it when the tensile is around 175,000 lb. per square inch and the elongation not less than 10%. In this condition almost all required sections can be formed, and thus finished sections already at high strength can be obtained without any further heat treatment. Heat treatment of a non-stainless alloy further requires sand blasting and then precautions against corrosion being taken, such as painting or electro-plating. All this is eliminated in using a stainless steel, cold rolled to high strength.

A hard rolled 18–8 alloy strip can be annealed by heating to a high temperature and quenching. It is this property that is so strangely similar to copper and quite different to the properties of most alloy steels, where the heating and quenching method is used to harden instead of soften. And, it is this property which makes the 18–8 alloy peculiarly suitable to spot welding. The very welding process is a repetition of the above method of annealing. For instance, two strips are held tightly together between copper electrodes of suitable diameter and with sufficient pressure to insure proper contact of the metal. An electric current is then turned on for a small fraction of a second passing between the two electrodes through the two metals to be welded. The metal at this point is heated almost instantly to a fusion temperature, and then the heat is conducted away by the copper electrodes and the surrounding cold metal even more rapidly than the chilling of a body of metal being quenched in water. The result is—a weld is made of annealed metal which gradually radiates out to the hard material unaffected by the heat. A tough malleable weld is therefore the result, admirably suited to fatigue.

In order to emphasize the advantage of the above type of weld, it is necessary to describe what happens when two sheets of chrome molybdenum alloy are spot welded together. Chrome molybdenum alloy is very popular in aircraft construction because it is particularly suitable for torch welding. It is commonly known as chrome moly and is hardened to any required strength up to 240,000 lb. per square inch by heating to a high temperature and then quenching, at which point it is extremely brittle. It is then drawn from some temperature suitable to the final strength required. If two sheets of chrome moly are spot welded together, the rapid conduction of the heat away from the heated area causes a ring of glass hard metal to form around the spot. A sudden slap broadside on a table is generally sufficient to rupture the weld.

Such a weld can, of course, be made satisfactory and reliable by subsequent heat treatment. A further snag exists, however. Light weight and great strength frequently necessitate fairly complicated built-up structures. A tapered wing beam about sixteen feet long in spot welded, chrome moly sheet was built and was heat treated under the most advantageous conditions in an electric furnace. An astonishingly large proportion of the welds were found broken, although the ones which remained were tough and satisfactory. The mere heating up during the heat treat had brought about expansion, causing warping and internal stresses sufficient to break a great many of the welds before they could be normalized and brought to the same condition of toughness as the surrounding metal. So much for the spot welding of chrome moly, and for that matter any metal which goes brittle on chilling from a high temperature. The 18–8 alloy, on the other hand, leaves a tough

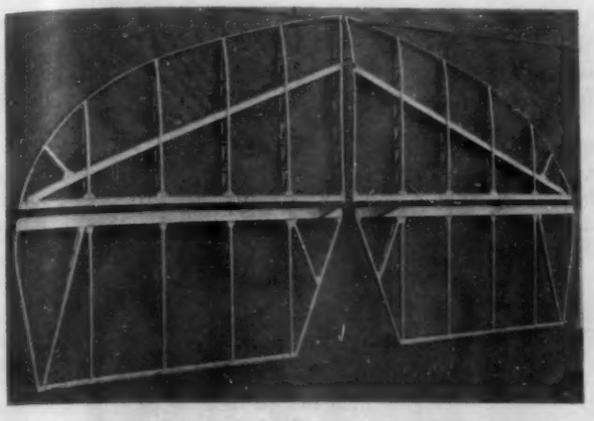


Fig. 2—Airplane Tail Surfaces of Stainless Steel Fabricated by Welding

and malleable weld quite suitable to withstand the fatiguing vibrations encountered in aircraft.

Spot welding has, of course, been successfully used in the automotive industry for some time, but it has been principally used on mild steel, where the carbon is exceptionally low and the chilling of the spots does not cause the same brittleness to result as it does in the higher strength alloy steels. Where electric spot welding is used for alloy steels in motor car work, subsequent heat treatment is generally a simple matter, due to the simplicity of the structures being welded, where expansion difficulties tending to rupture the welds do not come into the problem.

The 18–8 alloy has an unfortunate property which must not be lost sight of. When heated to a temperature between 500° and 900° C., the carbon tends to come out of solution and combine with the chromium, forming chromium carbide which concentrates along the crystal faces in the metal, and when this occurs the steel ceases to be stainless and becomes subject to a type of corrosion which is exceedingly dangerous. When corrosion sets in on such a piece of metal, it follows down the crystal faces into the heart of the metal causing what is called an "intergranular corrosion," with the result that the metal tends to disintegrate and fall to pieces. If a welding torch is used on the 18–8 alloy, it is almost impossible to avoid this condition occurring at some point between the weld proper and the surrounding metal unaffected by the heat of the weld, with the result that this part is readily subject to corrosion and is a source of considerable danger in aircraft structures. In a spot weld this same range of temperature must, of course, be passed through, both while the welded part is being heated and while being cooled. The reason the same area of corrosive metal does not occur around the spot weld is because the heating and cooling is so extremely rapid that the carbon has no time to come out of solution. The cooling of a spot weld is even more rapid than quenching a mass of metal when annealing, whereas in a torch welded part the length of time that the metal is in the critical range where the carbon does deposit is a matter of at least a minute or two.

Tests do show that a spot weld on an 18–8 alloy is the first part to corrode. The corrosion, however, is very materially delayed and no serious difficulties have as yet been encountered with it. An amphibian with some stainless steel parts was inspected on its return from the tropics, having operated in the Gulf of Mexico for more than a year. On inspection, a considerable amount of red deposit was found concentrated along the stainless steel trailing edge of the wing. This rustlike deposit, however, easily came off by scratching with the thumb nail and the polished steel beneath appeared perfectly intact. The only place where any etching of the 18–8 alloy could be noticed was where some ordinary iron wire was in contact with it. It could be noticed that the surface had been etched but the strength of the member was intact even though its original thickness was only ten-thousandths of an inch. The amount of metal lost in corrosion could not even be estimated although the ordinary iron wire disintegrated entirely on handling.

The operation of spot welding in itself has also been a problem. The margins of safety in aircraft structures are of necessity very limited due to low weight requirements, and it is on this account that only the finest and most reliable means of welding or fastening of parts together can be used.

When welding investigations were first started, two supposedly automatic welders were purchased and it was found necessary to completely revise the control mechanisms in order to obtain satisfactorily reliable welds of known strength. There are several variables in the control of spot welding and the suitability of a machine for general work largely depends on the facility of changing these variables, and of knowing the values in use while welding. For instance, on the rebuilt machines the pressure is controlled by varying the compression of a spring and a calibrated indicator tells the operator at a glance what pressure is being used. With this scheme the pressure can be changed in a few seconds by turning a nut and lock nut and pressures reading directly in pounds are available at all times.

The development of a suitable timing switch was a more difficult problem. One was finally developed in which the time by oscillograph record is accurate to the nearest half-cycle. The time is controlled by turning a knob and can be adjusted in steps of one cycle from one to twenty cycles.

A new type of contact point was installed that does not burn and pit, as was the case with the old machines, and is still the case with most commercial spot welders. This trouble was overcome by the use of spring arcing points outside the area of the main contacts.

At the same time that the development of suitable welder controls was going on, an endeavor was made to learn what strengths could be relied upon in welds under various conditions of thickness and diameters of spots, etc. Values of current, time and pressure, and the size of electrodes that should be used under different conditions were gradually ascertained. Generally speaking, it was found that the shortest time possible, consistent with the accuracy of the timer, gave the best results. This, it is believed, is bound up with the more rapid heating and cooling taking place in a short time weld. In other words, the shorter the time the less the surrounding metal is affected by welding heat and the

Fig. 3—Stainless Steel Airplane Wing Spot Welded

more rapidly is the welded portion chilled, thereby allowing less of a change in the metal structure to occur. The deposition of any chromium carbide out of solution is in this manner entirely avoided.

Another problem in the handling of stainless steel for spot welding has been to design parts so that the welder electrodes could easily reach points where welding was required. This part of the problem has been attacked in two ways; one has been to simplify the structure so that the weld could be easily reached, and the other has been to develop trick shapes of electrodes to use where the design could not be readily simplified. The making of trick electrodes to get into queer position has been found very difficult and much the easiest way to handle the problem is to simplify the design. However, the two developments are going along hand in hand and some two to three dozen different standard shapes of electrodes have been developed which help to handle some rather difficult positions. This problem, however, is an endless one and will continue as long as spot welding is used.

SECTION ACTIVITIES

(*Continued from page 4*)

CLEVELAND

The March meeting of the Cleveland Section was held on the 30th. Mr. W. H. Ludington, Manager of the Applied Engineering Department of the Air Reduction Sales Company's laboratories at Jersey City, spoke on the Theory and Practice of Oxy-Acetylene Cutting. Mr. Ludington's talk covered all phases of cutting with hand torches and by automatic and semi-automatic machines. The paper covered not only the application of the method to ordinary low carbon steels, but also covered high carbons and various alloys. Mr. C. H. Wills, General Manager of the William B. Pollack Company, spoke on the uses they make of oxy-acetylene cutting in heavy steel plate construction which goes into blast furnaces, heavy machinery for sugar and steel mills, and hot metal cars.

LOS ANGELES

The regular meeting of the Los Angeles Section was held on February 18th at the Mona Lisa Restaurant. The following elections were made:

Turner Smith, Chairman; G. J. Carroll, Vice-Chairman; M. H. Turner, Secretary and Treasurer.

Other members of Executive Committee are: Frank A Lango, Paul E. Jeffers, C. J. Nyquist, J. J. Bruton, H. P. Etter and J. O. Kilian.

Mr. A. P. Johnson of Los Angeles gave a most interesting and instructive paper, entitled: "Welding of Stainless Steels." Mr. Johnson mentioned some of the more important industrial users of stainless alloys and pointed out various types of applications, types of welding rod, best procedure, grinding after welding, how to prevent buckling, spot welding and soldering. Following Mr. Johnson's talk, Mr. Turner Smith opened the discussion by a series of questions which brought out additional information relative to this subject.

A meeting of the Los Angeles Section was held on March 24th at the Mona Lisa Cafe. Special committees were appointed as follows: Program, Pressure Vessels, Membership, Structural, Piping, Job Shop.

Mr. Stanley Levyn, of the Acme Electric Welder Corp., delivered a paper on Resistance Welding, stressing the several types of resistance welding; kind of metals most readily welded; machine characteristics, and industries which use resistance welding.

The following meetings were announced:

April 21st—J. J. Bruton in charge—Dinner at the Miramar Hotel, followed by an inspection trip through the Douglas Airplane Plant.

May meeting—C. J. Nyquist in charge—Dinner at the Frank Wiggins Trade School, followed by an educational program at which it is hoped the students from the trade school will be present.

The Section has been called upon to assist the City of Los Angeles in the revision of its code dealing with pressure vessels and piping.

NEW YORK

The next meeting of this Section will be held on May 25th. The subject will be Stainless Steel Welding. The names of the authors will be announced in the next issue of the JOURNAL.

PHILADELPHIA

There was an attendance of about sixty at the March 21st meeting of the Philadelphia Section, who heard Mr. Harry Pierce, Welding Supervisor, New York Shipbuilding Company, tell of "Welding Problems in a Shipyard."

At the April meeting which will be held on the 18th, Mr. F. Eder, of the New York Office of Robert W. Hunt Co., will talk on "Inspection of Welded Steel Framing in Buildings."

The next meeting will be the Annual Meeting and new officers will be elected and installed.

PITTSBURGH

Three papers were presented at March meeting of Pittsburgh section.

The welding of straight chrome and 18-8 alloy steels and aluminum by the various welding processes was discussed. L. W. Hostettler, Engineer for the Allegheny Steel Company, explained the physical and chemical characteristics of the various alloy steels produced by his company and then described the welding technique required for the various metals. He analyzed some of the difficult problems which the welding fabricators have experienced and told how they were overcome.

D. I. Bohn, engineer for the Aluminum Company of America, described at length the extensive experiments which his company has been conducting with the resistance welding of aluminum. Aluminum can be successfully spot, seam and butt welded if the proper equipment and sufficient pressure is provided. The proper design of the electrodes is also important. He mentioned that they have secured better results with a pure copper electrode than with the hard copper alloy type.

G. O. Hoglund, also an engineer for the same company, described the welding characteristic of aluminum and how they should be considered when using either the gas or arc welding process. He explained in detail the proper welding procedure to use when using either one of the processes. The proper equipment, electrodes and fluxes to select and how they should be used were discussed in detail.

The meeting was brought to a close by the presentation of a reel of motion pictures depicting the testing of welded aluminum tanks conducted by the Petroleum Institute. The tanks were subjected to drop, pressure and fire tests with no weld failures.

Professor Frank P. McKibben will be the speaker for the April meeting which will be held the 13th of the month. It will be a joint meeting with the Pittsburgh section of the A. S. C. E.

PORTLAND

The monthly meeting of the Portland Section was held on March 23rd. Following the business meeting, the meeting was turned over to the Steel Tank & Pipe Co. for the showing of three reels of motion pictures showing the shop fabrication and field installation of a 48 in. electric welded water supply line for the City of Everett, Washington.

SAN FRANCISCO

For many months past the officers of this Section have not called a meeting due to the small attendance at the last few meetings held.

A meeting was held at the Athens Athletic Club, 11th and Clay Sts., Oakland, Friday evening, March 25th, at 8:00 P.M. to discuss whether or not there is enough interest in the Section to hold further meetings.

Mr. W. A. F. Millinger, Pacific Coast Vice-President of the American Welding Society, who is connected with the Shell Oil Company and has just returned from a trip to the Orient, showed some very interesting moving pictures and talked upon the subject "Welding in the Orient."

Current Welding Literature

Alloy Steel Welding. Welding Non-Magnetic Steel Alloys, P. Orr. Machy. (N. Y.) (March 1932), vol. 38, no. 7, pp. 489–49.

Aluminum Welding. Practical Points on Welding Aluminum, E. Searles. Machy. (N. Y.) (March 1932), vol. 38, no. 7, pp. 536–537.

Applications. Industrial Concerns in England Advocate Welding, E. D. Lacy. Welding (Feb. 1932), vol. 3, no. 2, pp. 99–102. Typical examples of equipment for chemical, gas, cement and shipbuilding industries fabricated by welding.

Atomic Hydrogen. Progress in Atomic Hydrogen Welding, S. Martin, Jr. Iron Age (March 3, 1932), vol. 129, no. 9, pp. 537–540.

Buildings. All-Steel Arc-Welded Building Erected in Pittsfield. Constructor (Feb. 1932), vol. 14, no. 2, pp. 29–30.

Coal Mines and Mining. Scientific Welding for Colliery Repairs, C. W. Brett. Colliery Guardian (Feb. 3, 1932), vol. 144, no. 3710, pp. 248–250.

Compressed Air. British Standard Specification for Forge Welded Steel Air Receivers. Brit. Eng. Standards Assn.—Standard Specification No. 428—1931, 14 pp.

Costs. Estimating Oxy-Acetylene Pipe Welding Costs, J. H. Zink. Welding (Feb. 1932), vol. 3, no. 2, pp. 111–113.

Costs. Economics of Quality Welding, R. E. Kinkead. Welding Engineer (Jan. 1932), vol. 17, no. 1, pp. 43–44. Why profits expected from welded construction sometimes fail to materialize.

Cutting Tools. Welded Tips for High Speed Tools, T. K. Vincent. Welding (Jan. 1932), vol. 3, no. 1, pp. 22–25. Experiments conducted at Watertown Arsenal, with various welding processes to determine possibilities in making special cutting tools; use of chromium-tungsten-vanadium and molybdenum rod as electrode.

Distilling Apparatus. Electrically Welded Fractionating Columns. Engineer (Feb. 19, 1932), vol. 153, no. 3971, p. 219. Also in Engineering (Feb. 12, 1932), vol. 133, no. 3448, p. 204.

Elect ic Arcs. Forces of Electric Origin in Iron Arc, F. Creedy. Am. Inst. Elec. Engrs.—Advance Paper No. 32–41, meeting Jan. 25–9, 1932, 8 pp.

Electric Welding, Arc. Automatic-Arc Welding, G. G. Landis. Boiler Maker (Feb. 1932), vol. 32, no. 2, pp. 30–32.

Electric Welding, Arc. Strong Tough Welds Made Rapidly, G. E. Doan. Metal Progress (Feb. 1932), vol. 21, no. 2, pp. 39–43. Methods of obtaining sound welds by proper heat treatment, use of proper electrodes, etc.

Electric Welding Machines. Designing Modern Arc Welder, F. B. Hornby. Gen. Elec. Rev. (Feb. 1932), vol. 35, no. 2, pp. 122–125.

Electric Welding Machines, Arc. Oscillator Stabilizes A. C. Welding Arc, J. B. Gibbs. Elec. World (Feb. 27, 1932), vol. 99, no. 9, p. 405.

Electric Welding Machines, Resistance. Sixty 8-Inch Pipe Welds per Hour, M. Clark. Welding Engineer (Jan. 1932), vol. 17, no. 1, pp. 29–31. Factors involved in design of modern heavy-duty flash welders to secure fast production and flexibility.

Electric Welding, Resistance. New Resistance Welding, M. L. Eckman. Welding Engr. (Feb. 1932), vol. 17, no. 2, pp. 42–44.

Gas Plants. Electric Welding on Gasworks, E. Marshall. Gas Engr. (March 1932), vol. 49, no. 3, pp. 129–130 and 131.

Hard Facing in Machine Manufacture, J. C. Huston. Machy. (N. Y.) (March 1932), vol. 38, no. 7, pp. 513–514.

Hard Facing in Steel Industry, W. A. Moore. Welding (Feb. 1932), vol. 3, no. 2, pp. 88–91.

Houses. Welding Extensively Employed in Steel House, H. Dubin. Welding (Jan. 1932), vol. 3, no. 1, pp. 15–19 and 27.

Houses. Arc Welding Brings Strength and Economy to Residence Building, J. F. Lincoln. Welding (Feb. 1932), vol. 3, no. 2, pp. 92–95. Cost data for first arc-welded steel frame house recently completed in Cleveland.

Machine Shop Equipment. More Welded Shop Equipment, A. F. Davis. Am. Mach. (Feb. 25, 1932), vol. 76, no. 8, pp. 260–1.

Manganese Steel Welding. J. H. Hall. Welding Engineer (Jan. 1932), vol. 17, no. 1, pp. 39–41. Typical applications of manganese steel welding addition of nickel to welding rod or electrode greatly reduces harmful effect of overheating parent metal.

Pipe Lines. Management of Labor on Pipe Installation, G. E. Deteridge. Welding (Jan. 1932), vol. 3, no. 1, pp. 39–42.

Pressure Vessels. Designing and Testing Welds in High-Pressure Vessels, W. Spraragen. Iron Age (Feb. 4, 1932), vol. 129, no. 5, pp. 340–343 and (adv. sec.) 30. Continued review of safe designs for head construction, discussing necessity for stress relief and outline of various approved methods of inspecting and testing welds; methods of insuring ductility in welded joints.

Pressure Vessels. Welded Boiler Drums, C. A. Adams. Mech. Eng. (March 1932), vol. 54, no. 3, p. 222.

Rails. Saving Money in Railroad Yard, C. Wise. Welding Engineer (Jan. 1932), vol. 17, no. 1, pp. 34–36.

Sheet Metal Welding Formulae, Seferian. Sheet Metal Industries, vol. 5, nos. 2, 3, 6 and 8 (June 1931), pp. 120, 122 and 124; (July), pp. 209–210; (Oct.), pp. 447–448; (Dec.), pp. 585–586.

Shipbuilding. Electric Welding in Ship Construction. Engineering (Feb. 12, 1932), vol. 133, no. 3448, p. 183.

Standardization. Importance of Standardization in Welding Industry, C. G. Watson. Welding (Jan. 1932), vol. 3, no. 1, pp. 30–34. Survey of present conditions in welding industry with particular regard to press made towards standardization.

Steam Pipe Lines. Modern Welded Pipe Installation. Power Plant Eng. (March 15, 1932), vol. 36, no. 6, pp. 253–254. Outline of welding details in improved design of heating installation for large building in Middle West; strong joints, space economy, flexibility and speed of erection are advantages.

Steel Structures. Report of Steel Structures Research Committee for Period Ended March 31, 1931. Dept. Sci. and Indus. Research, 1931, 276 pp. Report of committee appointed in August 1929, to review present methods and regulations for design of steel structures, including bridges, also application of modern theory of structures, and to make recommendations for more efficient and economical design.

Street Railroad Tracks. Track Joint Construction Methods Used by Third Avenue Railway. Transit J. (March 1932), vol. 76, no. 3, pp. 132–134. Outline of equipment and methods employed by Third Avenue Railway System, N. Y. City, in making track joints; results of tests with electric butt-welded rails.

Testing. Will He Get Job? Welding Engineer (Feb. 1932), vol. 17, no. 2, pp. 31–35. Qualification tests applicable to sheet and plate welding, pipe welding in buildings, pipe line welding, structural welding, tank welding and tube welding.

Tests of Welding and Weld Metal and Their Interpretation, A. F. Burstall. Metal Industry (Lond.) (Jan. 29, 1931), vol. 40, nos. 5, 6 and 7 pp. 153–155; (Feb. 5), p. 175 and discussion; (Feb. 12), pp. 195–6.

Waterwheels. Welding of Water Wheels. Nat. Elec. Light Assn.—Proc., vol. 88, meeting June 8–12, 1931, pp. 573–584.

Welding. Recent Developments in Manufacture of Welded Structures, L. Miller. Mech. World (Jan. 29, 1932), vol. 91, no. 2352 and 2353, pp. 104–107 and (Feb. 5), pp. 128–130. Oxyacetylene and electric welded structures and machines; comparison of fabricated steel and cast-iron parts; standard chart indicates on drawings type of joint; automatic atomic hydrogen welding; structure of weld metal; testing of welds.

Cutting and Welding Tips for Torches

▼ STANDARDIZED cutting and welding tips, interchangeable with various types of torches; also apparatus, accessories and complete outfits—obtainable from one responsible source. Prices unbelievably low. High quality and workmanship.

Write NOW for complete Catalog

TIPS • INC.

515 Cathedral Street ▼ BALTIMORE, MD.

THE MOST NEARLY LIMITLESS SERVICE THE WORLD AFFORDS

COUNT, if you can, the value of a given telephone call. It may cost you five cents or less. It may have profited you five dollars or five hundred dollars. It may have brought you five friends or five hours of leisure, or five years more of life.

There is no way to measure the full value of the telephone, for it is the most nearly limitless service the world affords.

It is yours to use as you will, when you will, wherever you will. It knows no time or distance, class or creed. Over its wires come messages of hope and cheer, of friendship and love and business, of births and marriages, of every active moving step in life and living. Its many millions of calls each day are the vocal history of the nation—the spoken diary of the American people.

Hundreds of thousands of employees, eighty-five million miles of wire, and a plant investment of more than four thousand million dollars are at your service whenever you pick up the telephone. Yet the charge for local residential use is only a few cents a day. Infinite in value . . . low in cost . . . your telephone. In the next moment it may ring with a message that will change your destiny.

AMERICAN TELEPHONE AND TELEGRAPH COMPANY

Our Advertisers Are Supporting the Society